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MISSOURI BUREAU OF GEOLOGY AND MINES.
E. R. BUCKLEY, Ph. D., Director and State Geologist.

Vol. II, 2nd Series.

THE QUARRYING INDUSTRY OF MISSOURI

BY

E. R. BUCKLEY AND H. A. BUEHLER.

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RED GRANITE.
Boulders resulting from weathering, Graniteville, Mo.

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LETTER OF TRANSMITTAL.

BUREAU OF GEOLOGY AND MINES,
ROLLA, April 10, 1904.

To the President, Governor A. M. Dockery, and the Members of the Board of Managers of the Bureau of Geology and Mines:

Gentlemen—I have the honor and pleasure to transmit to you a report of the Quarrying Industry of Missouri.

The field work for this report was begun in the summer of 1902 and has been carried on, as opportunity would permit, up to the present time. Mr. H. A. Buehler has examined all the important quarries in the State, giving special attention to those engaged in the production of stone for building and ornamental purposes. I have examined the quarries in the more important districts alone and in company with Mr. Buehler.

Not only have the quarries been examined, but buildings, monuments and pavements, constructed out of Missouri stone, have been examined, and samples of the stone have been tested in the laboratory. Every important means, by which the durability of stone can be determined, has been used.

There are many small quarries, worked only to supply the local market, which have not been examined. It is impossible, however, to determine the names and locations of these quarries without spending several weeks in most of the counties in the State. Therefore, this report has been devoted to a discussion of the most important and best developed quarries. It is thought that no quarry from which stone is shipped has been omitted from this report, while there have been included descriptions of many quarries which are worked solely to supply the needs of the community in which they are located.

Careful statistics of production have been collected and compiled showing that this industry adds to the permanent wealth of the State over two and one-half millions of dollars a year. It is expected that this report will give the public information which will result in a much more extensive use of Missouri stone.

That portion of the report embodying the descriptions of the quarries—Chapters V, VI, VII, VIII, IX and X—was written by Mr. Buehler.

Mr. Buehler made most of the physical tests, made all the chemical analyses and prepared the maps and illustrations with the exception of the drawings accompanying the tables in Chapter XI. The remainder of the report, including Chapters I, II, III, IV, XI, XII, the Introduction and the Appendix, was written by myself.

I remain, very respectfully, your obedient sir,

E. R. BUCKLEY.

ACKNOWLEDGMENTS.

The successful completion of a report of this character depends very largely upon the interest manifested in the work by quarry owners and operators. To all of these the authors are under deep obligation for many courtesies extended. We are indebted to the Universities of Illinois, Kansas and Wisconsin for the use of their laboratories in testing the samples of stone collected. We also desire to extend our sincere thanks to Dr. J. H. Britts of Clinton, Sidney J. Hare of Kansas City, and Judge John L. Bogy of Ste. Genevieve for many courtesies. Our thanks are also extended to the different railroad systems in the State for the very generous assistance which they have rendered.

INTRODUCTION.

During the administrations of Winslow and Keyes, special reports were published on "Lead and Zinc," "Coal," "Mineral Waters," "Iron Ores" and "Clay Deposits." Up to the present time, reports have not been published on the quarrying industry, the lime and cement industries, soils, road materials, barite and asphaltic limestone and sandstone. This report deals with the quarrying industry. It is the plan of the Bureau to follow this with report on the "Lime and Cement Industries," and this in turn by other reports on resources that have not yet been investigated. Later, it will be necessary to revise and publish new editions of the special reports which we now have. These reports are thought to be the most valuable publications of the Bureau. They bring together a vast amount of information which serves not only to educate the public at large, but also to attract capital seeking investments.

To fully understand the characteristics of stone used for buildings and other constructions, one should be familiar with the composition and manner of occurrence of the common minerals and rocks. In discussing the chemical, mineralogical, and physical tests of stone, it is often necessary to use terms with which the general public is not familiar. In order to make this report more intelligible, an appendix has been added in which the composition and kinds of minerals and rocks, and the common rock textures and structures are discussed.

The first three chapters of this report are devoted to a discussion of the demands and uses of stone, the necessary considerations in the selection of stone, the properties of building stone, and the methods of determining the value of stone for different uses. Chapter Four is a brief geological history of Missouri. The fifth, sixth, seventh, eighth and ninth chapters embrace a complete discussion of all the important quarries in Missouri, giving the manner of occurrence of the stone, its color, composition, strength, durability, etc. Chapter Ten is devoted to a discussion of the areas from which suitable stone for different uses may be obtained. In this chapter it is not intended to point out the uses to which the stone in each individual quarry is suited, but rather to give a general idea of

the wide distribution of good building stone in the State. Chapter Eleven is devoted to a discussion of the physical tests, and contains tables showing the results of the laboratory examination of samples of stone from twenty-nine different quarries. It is thought that this series of tests is very complete and that it will be especially valuable to architects and builders in the selection of stone to be used in the construction of important buildings.

This report is accompanied by a geological map of Missouri on which the important quarries have been located. The geology on this map has been reproduced from a map published in an earlier report of this Bureau. This report also contains sketch maps showing the location of the quarries in the vicinity of St. Louis, Kansas City and Carthage. The exact location of all the quarries can be obtained by reading the descriptions in the body of the report. Half-tone cuts of some of the more important quarries and of the buildings in which Missouri stone has been used, constitute the chief illustrations in this report. The reader can obtain a good idea of the size of the quarries and the adaptability of the stone to building constructions by examining these in conjunction with the descriptions of the various quarries.

Several plates have also been inserted to illustrate the results of the laboratory tests. It is interesting to know the manner in which different stones break, when subjected to a pressure greater than their ultimate strength. Accompanying these plates are a number of photographs of thin sections of granite, sandstone and limestone, as seen through the microscope. These illustrations give one an idea of the size and shape of the individual grains of which the different kinds of rock are composed. Since the strength and durability of a stone depends chiefly upon its composition and texture, these illustrations are especially instructive.

The quarries which are engaged exclusively in the manufacture of quicklime and cement have been given very little attention in this report. It is the intention to publish a volume on the lime and cement industries in which these quarries will be fully described.

Reliable statistics have been collected and compiled to show the value of the output of stone from Missouri in 1903. This is very interesting in so much as it shows a production far above that reported by the United States Geological Survey.

The people in this State have a very meagre conception of the importance of the stone industry. Very little is known in some parts of the State as to the value of the granite, limestone and sandstone which is shipped to all parts of the Mississippi valley.

The red granite which is quarried in the southeastern part of the State has an enviable reputation among granite workers in this and neighboring states. The consumption of this stone for monumental and building purposes is increasing, and it is thought that before many years it will replace almost entirely the eastern red granites which are now sold so extensively within the State. The limestone and sandstone quarries are among the most important in the Mississippi valley. The Carthage limestone is unexcelled as a building material by any limestone in the middle west. In color it is unsurpassed and in strength and durability, it is the equal, if not the superior, of any stone with which it comes into competition. The other limestones which are being quarried supply an ever-increasing home market. The sandstone quarries at Warrensburg and Miami produce stone which finds a ready market in the southern states and they constitute one of the valuable sources of sandstone in Missouri.

The caves in the Ozark region contain large deposits of onyx which in some places may be suitable for interior decorative purposes. It is not being exploited at the present time, owing to the distance of the deposits from the railroads and the inferior quality of that which has thus far been quarried.

In the vicinity of Seneca there are extensive and valuable deposits of tripoli from which are produced water filters of superior quality. The sandstone quarries at Pacific, Klondike, Gray's Summit and Silica produce sand or quartz which is unexcelled for the manufacture of glass. The Burlington and Trenton formations consist of limestone which makes a quicklime of unsurpassed excellence. The shale and limestone of the Carboniferous are in many places well suited to the manufacture of Portland cement. In Vernon and other counties in the western part of the State there are extensive deposits of asphaltic sandstone, as yet undeveloped, which constitute a valuable source of material for paving.

Altogether, the building stones of Missouri constitute one of her most valuable natural resources. It is one which adds millions each year to her permanent wealth, and one without which she would suffer many inconveniences.

CHAPTER I.

DEMANDS AND USES.

Among the least attractive and yet most valuable resources of a country are the products of the stone quarries. Every city, town and village is made wealthier by the occurrence of stone which can be used in the ordinary, rough forms of masonry construction. In some places the rock exposures are so numerous and the needs of the people in this direction so limited that no large quarries are developed. The farmers during the winter months frequently haul stone into town, as they do wood, selling it for foundations, sidewalks and other purposes. In the smaller towns the demand for stone, rough or dressed, is very limited and although good stone may be obtainable from the local quarries, it is often cheaper to purchase the same from a larger quarry located at a distance.

Stone is used for a multitude of purposes and it may be necessary only to mention a few of these to bring to the attention of the reader the importance of the quarrying industry. A greater part of the stone quarried is used for constructional purposes, but an important part is used in conjunction with other materials for the production of what may be termed artificial or manufactured products. The uses of stone in its natural state may be considered under the heads of Building, Bridge, Culvert, Paving, Concrete, Railroad ballast, Curbing, Engraving, Abrasives, Insulators, Ornaments, Filters, Furnace, Post, Fence, Retaining Walls, Breakwater, Monument and Miscellaneous. Stone used for artificial products may be considered under Glass, Cement, Lime, Fertilizer, Pottery, Paint, Chemicals, Gas, etc.

BUILDING STONE.

Under "Building stone" it is customary to include all stone used in buildings, public and private, of any description. In most buildings the stone is cut and dressed before being used, although frequently, where the walls are concealed or the artistic feature is unimportant, the stone is used as quarried, being cut only by the mason for the purpose of fitting the pieces into the wall. The walls of a building may be entirely or only in part constructed out of stone. Frequently the front is veneered with

stone while the remainder is built out of brick, terra cotta or cement concrete. In the larger cities one may observe long rows of what appear to be stone residences, which in reality have only their fronts veneered with stone. In the cities the tendency has been to build the fronts of business blocks and residences out of stone and the back and side walls out of common brick. In the rural districts and in the small towns and cities the tendency has been to construct the back and side walls out of rubble stone and the front out of pressed brick. In either case, the purpose has been to make as attractive a front as possible at a minimum cost.

Rubble stone is used very generally for the construction of foundations to buildings. The steel frames of many of our large buildings rest on thick stone piers built out of footing stone. The foundation courses above the ground are usually built out of dressed ashlar blocks, while those below are random rubble masonry.

Of late years brick and cement concrete have in a measure supplanted stone for foundations, as well as for walls and other parts of building constructions. But, in any case, it is only a change in the form in which the stone is used. Brick and terra cotta are produced mainly from shale—an argillaceous stone which is too soft for building—while concrete is a mixture of cement and broken stone. Whether it be brick or concrete, stone must ultimately be used in one shape or another. Where the walls are of brick and terra cotta, cut stone is frequently used for the sills, caps and other parts of the building commonly known as the trimmings. The roofs of buildings are being more generally constructed out of slate, tile and metal sheeting than ever before. Wooden shingles are comparatively expensive today, and it will not be long, with the present rate of depletion of our forests, before they are altogether replaced by more permanent materials. In the large cities the danger from fire has compelled the use of slate, roofing tile and other fire proof materials, even before the increased price of wooden shingles practically forced them out of the market.

In the interior, stone is used mainly for decorative purposes. The floors of many of our public buildings are built out of marble, slate or cement concrete. Stair-cases, columns, wainscoting, wash basins, switch boards and many other interior constructions call for stone in one form or another.

In many of the rural districts, in Missouri, brick is expensive on account of the cost of transportation. As a result stone has been used for many purposes, such as chimneys, fire places and ovens.

It is evident from the above that in the construction of buildings,

alone, there is a wide demand for stone. The rapid advance in the price of lumber has increased the use of other and more permanent materials in nearly all avenues of building construction. Soon, as a matter of economy, buildings everywhere distant from our pine forests, will be constructed out of stone, brick, concrete, terra cotta or some other permanent material in preference to wood. As our population increases and civilization advances our people will erect better and more durable buildings. In all this change or evolution through which we are passing the quarryman will be called upon to provide, in one form or another, an increasing quantity of stone.

The wooden buildings in all our large cities are gradually being torn down, and their places are taken by substantial fire proof structures built of stone, brick, terra cotta, concrete and steel. The home of the working man, as well as that of the capitalist, is now being built of stone, brick or concrete. There may come a time when a residence built out of wood will be a luxury only to be enjoyed by the rich.

MONUMENTS.

The demand for monuments, mausoleums and headstones keeps pace with our rapidly increasing population. Millions of burial places are marked with slabs, columns or shafts of marble, limestone or granite. The demand for building stone may fluctuate, but that for monuments increases with the advance of civilization.

Each year the demand is for more durable material, and as a result marble and limestone are being gradually supplanted by granite, rhyolite and other igneous rocks. People prefer a small, durable monument to one which is large and temporary. The superiority of granite over all kinds of marble and limestone can no longer be questioned. The lettering on marble slabs and columns in a climate such as ours, soon becomes illegible and all signs of the original polished surface are soon effaced. The white glistening marble is more distasteful to the eye than the more subdued red and gray tints of the granitic rocks. Marble monuments and slabs are now erected mainly in the rural districts where the relative permanence of different stones is little known. Thousands of people who purchase headstones and monuments do not know any difference between marble and granite, only that the former is less expensive.

Sandstone has been used in some localities for monuments. This stone is seldom uniform in texture, weathering unevenly and usually more rapidly than marble or granite. It can never be polished and for this reason is little used for monuments.

The extent to which a particular marble or granite is used for monuments is determined very largely by its reputation. The granite and

marble of the old world have long held a high place in the estimation of our people and we do not wonder at the use of Scottish or Scandinavian stone for some of the best of our monuments. The granites from Massachusetts, Vermont and Maine, have won a prestige in the markets through their past extensive use. The New Englander and Scotlander alike, feel that any rock from their native hills is worthy of any praise that can be bestowed upon it. They content themselves with a knowledge of the place from which it has been quarried and are proud to have their last resting place marked by a column of granite from their native country. The Scotchman does not always know a good granite from a poor one, but he loves his native land and every rock that comes from its moors and crags is dear to him.

The granites and marbles of this country are as strong and durable as those from Europe. The granite and marble of the central and western states is as strong and durable as that from New England. No more beautiful red granite can be obtained in the country than that which is quarried in the southeastern part of Missouri. The brilliant and subdued red colors are equal to those of the granites quarried in foreign countries or the eastern states.

The history of this country is not being written in the newspapers and books of today, but in the buildings and monuments which are being constructed in our great cities. Should our republic be destroyed, the records inscribed on monuments would furnish a large part of the history of our people. A stone which will crumble and decay in a century is unfit for a monument of any character. If we would erect more permanent monuments, to better preserve the history of a great people, they must be of granite, not limestone and marble. The demand for stone for monumental purposes is constantly increasing; and with this demand should come an increase in the development of the granite quarries of this State.

ROAD MATERIALS.

Stone is the most abundant, cheapest and most widely employed of all the materials used in street constructions. It is used in the construction of macadam and stone block pavements; in concrete foundations for curbing; for gutters; for sidewalks; for crosswalks; for bridge abutments; for culverts; and various other miscellaneous uses.

Foundations to pavements usually consist either of sand and gravel, wood in the form of planks, broken stone, brick, stone blocks or concrete. Wherever the foundation is broken stone, stone blocks or concrete, the materials from the quarry enter directly into the construction. Broken stone is probably the most widely used of any of the materials

mentioned for foundations. Both macadam and telford pavements are being used as the foundation to asphalt and brick pavements. Partly worn out stone block pavements are occasionally taken up, turned and relaid to serve as a foundation for asphalt or some other of the common pavements. Concrete is most commonly used as a foundation for asphalt, brick and stone block pavements. A concrete foundation is usually 5 or 6 inches thick and is composed of about 85 per cent. of broken stone in pieces not less than 1½ inches nor more than 2½ inches in their largest diameter.

The surface of the pavements may consist of either macadam, granite block, brick, asphalt, wooden block or sundry other materials. Macadam and granite block pavements consist almost exclusively of material furnished by the quarry. Paving brick are made out of soft shale which can scarcely be considered a quarry product. The surface of an asphalt pavement consists of about 10 per cent. of pulverized granite or quartzite, either of which must be obtained from the quarry.

In some cities asphalt pavements are constructed out of a bituminous or asphaltic limestone or sandstone which is quarried the same as any other stone. A limestone or sandstone which is suitable for this purpose should contain not less than 10 per cent. of bitumen.

Gutters are, as a rule, constructed either out of concrete or stone.

Curbing may be either stone, concrete or terra cotta. Up to within the last few years, both the curb and gutter were usually constructed out of stone. Lately, however, the stone has been in a measure replaced by cement concrete and terra cotta.

Sidewalks and *crosswalks* are constructed mainly out of stone, brick or concrete. In some localities, wood is used almost exclusively. Lumber, however, is becoming so costly, that stone, brick or concrete are found to be less expensive.

Culverts, hitching-posts and *stepping blocks,* all of which are classed as highway constructions, are in part built out of stone.

Thousands of *bridges* and *culverts* are being constructed and reconstructed each year along the public highways, the stone for which must be furnished by private quarries. The railroads are constantly building bridges and culverts, in the construction of which great quantites of stone must be used.

To a greater or lesser extent, in the construction of bridge abutments, concrete is replacing the stone which was used almost exclusively a few years ago. The use of concrete, however, simply calls for broken stone instead of stone blocks. In the construction of bridges or culverts, either along the railroads or highways, there will be a constantly increasing demand for stone.

The demand for permanent highway improvements has not advanced very rapidly except in the larger cities and towns of Missouri. The methods of improving the rural highways have changed very little during the last twenty years. It is true that the roads are worked, but the same repairs have to be made year after year and the road frequently remains almost impassable half of the time. Farmers have contented themselves with hauling half a load, on account of the depth of the sand or the thickness of the mud. At present, however, there seems to be an awakening among the people which is manifesting itself in the demand for permanent improvements to the highways.

Everywhere throughout the State, where stone is accessible, it will eventually be quarried and crushed for the construction of macadam pavements. Within the next decade hundreds of miles of roads in this State will be macadamized, requiring for these improvements hundreds of thousands of tons of crushed stone. The cities, towns and villages are improving their streets and no matter what kind of pavement may be laid, the quarry will be required to furnish the stone which enters into its construction.

In the construction of a macadam pavement, the hardest and most durable stone obtainable should be used. All stone is not suited for macadam. Rocks, which are soft, will pulverize under the horses hoofs, forming a fine dust during dry weather and soft mud during the wet months of spring and fall. A stone used for macadam should be sufficiently hard to withstand abrasion and the composition should be such that it will furnish constituents suitable for cementing the fragments together.

RIVER AND LAKE CONSTRUCTIONS.

Each year great quantities of rubble stone are being used in the construction of piers, breakwaters and cribs along our navigable lakes and rivers. As the rivers in this State are improved and the channels made more navigable, the demand for rubble stone will increase. The stone which is used for these purposes should have a capacity to withstand the attrition of the waves and should be practically insoluble.

RAILROAD BALLAST.

Railroad ballast consists, as a rule, either of crushed stone, gravel or burned clay. Of these three materials, crushed stone is considered the most desirable. With hundreds of miles of unballasted railroad tracks and many miles of projected lines in this State, one has positive assurances of a continued demand for stone for railroad ballast.

FURNACES.

In connection with the construction and operation of furnaces, large quantities of limestone and quartzite are used. The quartzite is mainly used in the form of ganister for lining the furnaces, while limestone is used as a flux.

ABRASIVES.

Much of the material used as an abrasive is simply finely pulverized quartz or silica, which is obtained by crushing and pulverizing quartz rock, either vein quartz or quartzite. The demand for this product of the quarry is relatively strong.

Among the abrasives must also be included grindstones, whetstones and oilstones. Grindstones and whetstones are simply sharp fine grained sandstones having a uniform texture. Oilstones are mainly novaculite which has an exceedingly uniform fine grain.

MISCELLANEOUS.

Among the miscellaneous uses for which stone is quarried may be mentioned sand for mortar, filters and foundry purposes. Fine grained, pure limestone is used extensively for lithographing. Less pure varieties are used in the manufacture of whiting, polishing powder, and similar substances. Quartzite, slate and shale are ground and used as paint pigments. Crushed stone and cement are used in the production of artificial stone. Soapstone is quarried for the manufacture of bath and laundry tubs, fire brick, stoves, hearthstones, mantles, sinks, griddles, slate pencils, foundry facings, paper making, lubricants, paint pigments, etc. Slates, blackboards, billiard tables and many other useful articles are manufactured out of slate.

ARTIFICIAL PRODUCTS IN WHICH STONE IS USED.

Sandstone, limestone and quartzite are the principal stones used in the production of artificial products. Sandstone and quartzite are pulverized or ground and used in the manufacture of glass, pottery and silica or sand brick. In some instances the sand or silica used for these purposes is obtained from unconsolidated river or lake deposits which ordinarily would not be included under the head of quarries. Limestone is used in the manufacture of cement, quicklime, fertilizers, carbon dioxide and other miscellaneous products.

Gypsum, which is calcium sulphate, sometimes occurs in the form of stone and is quarried for the manufacture of plaster of paris.

CHAPTER II.

NECESSARY CONSIDERATIONS IN THE SELECTION OF STONE.

Everywhere the attempt is being made to secure the very best materials that the money at hand can purchase. Ignoring, for the purpose of discussion, the item of cost, by which the mass of people are so largely controlled in their purchases, the selection of any stone will be determined (1) by its color and (2) by the capacity which it has to effectually withstand the atmospheric and other conditions under which it may be placed. The durability of a stone will depend, first, upon its inherent qualities which limit its capacity to withstand atmospheric and other conditions; and second, upon the atmospheric and other conditions of the immediate locality in which it is to be used.

COLOR.

The color which is most suitable or desirable in the construction of a building or a part of a building, depends mainly upon the location of the building. The color which is actually used is determined largely by fashion or the taste of the owner.

The predominant colors of stone are white, gray, brown, red, yellow, buff, blue, black, green and variegated.* As a rule a stone does not have a simple, but a composite color. The color that one ordinarily sees in a stone is the resultant of the blending of the colors of the several different minerals.

As a rule, the more complex the composition the greater will be the variety of colors in a rock. The larger the mineral particles the more distinct will be the colors of the individual minerals. On the other hand, the simpler the composition of the rock or the finer the mineral particles the more uniform will be the color. The uniformity of color is also controlled by the uniformity in the distribution of the mineral particles in the rock. The black nodules so common in some granites are due to the segregation in one place of mica, hornblende or some other of the ferruginous minerals.

*Speaking from a purely scientific standpoint all of these are not colors, although they are referred to as such in this paper.

On account of their homogeneous composition, the sedimentary rocks may more nearly approach a simple color than do the igneous. However, due to the process of seggregation above referred to, the sedimentary rocks may themselves have a more variegated or mottled color than the igneous. The different shades of brown, buff, yellow, red, gray and blue of the sedimentary rocks are mainly attributable to the occurrence of the oxide, carbonate or sulphide of iron, bitumen and carbonaceous matter in the form of graphite. The white and gray colors of marble, limestone and dolomite are attributable to the calcite and dolomite of which these rocks are mainly composed. The translucent and white colors of some sandstones are attributable to the quartz composing the stones. The green, gray and red colors of slate are due mainly to the iron and carbonaceous materials which enter into their composition.

In the sedimentary rock, iron may occur either as a secondary or an original constituent. When it occurs as an infiltration product, it often serves as a cement by which the original particles are bound together. It may also occur, however, in the shape of finely disseminated particles in the form of pyrite or hematite. Pyrite and marcasite may also occur in small cavities in the limestone, in which case, although secondary, it does not serve as a cement. Graphite, bitumen and petroleum frequently occur in limestone, marble and sandstone, imparting to these rocks a black, blue or grayish blue color. Occasionally the pores of the sandstone or limestone may be filled with bitumen forming what is termed a bituminous or asphaltic limestone or sandstone.

Among the red sedimentary rocks, there may be a wide variance in color, not only in the same quarry, but even in the same bed. Where the color of a stone is due to the infiltration of iron oxide, there is liable to be more or less of a variegated color throughout the formation. It is not uncommon to find red, yellow and buff colored sandstone in the same quarry. Frequently these colors may be present in the same bed. In some places the coloring matter occurs in regular bands, but occasionally it forms irregular, fantastic figures. Large and small brown and red spots often occur in white sandstone, while white spots are not uncommon in the brown and red varieties. Stone which is distinctly mottled or irregularly colored is known as variegated stone.

With respect to color, sandstones may be classed as red, brown, white, buff, gray and black. On the same basis, slates may be classified as red, black and green, these being the principal colors now being quarried. Limestone including dolomite, is usually white or gray, but frequently has a buff color. When impregnated with bitumen, it is black or brownish black. Marble and onyx have a wide range in color—white,

brown, red, green, black and variegated combinations of these colors being common.

The blending of the distinct colors of the different minerals in the igneous rocks results in the production of what has been termed a composite color. The size and distribution of the minerals, however, effect materially the color, since in some cases the crystals are sufficiently large to retain their individual tints, and at a reasonable distance the stone has a mottled or speckled appearance. At a distance, any of the granitic rocks, which may be mottled or speckled when closely inspected, appear to have a flat tint.

Granite, which is the chief igneous rock among building and monumental stones, is ordinarily classified as red and gray. There are, however, many shades of both colors, and whether a granite belongs to the first or second class depends mainly upon the proportions of red and white feldspar in the rock. Many granites contain both red and white feldspar, but wherever the former is sufficiently abundant to impart a reddish tint to the rock, it is usually classified as a red granite. In cases where the feldspar individuals are fine grained and light colored and biotite, amphibole and pyroxene are more abundant, subdued red or even a gray tint may be produced.

Whether a gray granite is light or dark, depends upon the size of the mineral constituents and the abundance and kind of ferro-magnesian minerals present in the rock. The lightest colored gray granites have a preponderance of white feldspar, quartz and white mica. The dark gray granites contain a preponderance of biotite, hornblende and pyroxene, with less feldspar and quartz.

Among the exceptional varieties of igneous rocks in use may be mentioned labradorite granite, which has a blue iridescent color, and rhyolite which is almost black. The labradorite granite is composed mainly of porphyritic individuals of labradorite, which impart to it the iridescent color. Rhyolite is not always black, but the color of that which is, may be mainly attributed to the semi-crystalline groundmass through which are scattered numerous small crystals of hornblende. Some of the igneous rocks have a green color, resulting from the presence of serpentine. The dull greenish gray color of many of the basic rocks, such as diorite, gabbro and diabase, is imparted mainly by the grayish green color of the minerals, pyroxene, amphibole and epidote, one or more of which occur as an essential constituent.

A stone cannot be expected to retain the color which it possesses when newly quarried, either for any great length of time or under all conditions of the atmosphere. A stone may be perfectly white when newly quarried, but a few years, or perhaps months, may change the

color to a buff or streak it with irregular patches of brown. Discolorations of this character are brought about by changes within the rock, on account of which certain ferruginous minerals are decomposed. A light colored stone may become gray or black from exposure, through the accumulation of dust particles deposited from the atmosphere. We therefore have changes in color brought about both by abstraction and accretion.

Changes in color due to abstraction are brought about, mainly, by the presence within the stone of minerals which are easily decomposed. The sulphide and carbonate of iron are often finely disseminated through a stone. When these minerals are exposed to the atmosphere, they are decomposed, one of the resulting products being oxide of iron. The yellow or brown oxide, known as limonite, which is thus formed, is carried in streaks over the surface destroying or marring the original color. In some of the limestones the iron sulphide is uniformily disseminated through the rock in such minute particles as to give the stone a bluish tint. In the quarry such a stone, near the surface, is usually altered to a buff color, while deeper down it passes gradually into the unaltered blue. Alteration usually begins along the joint planes, passing gradually inward toward the center of the blocks. Frequently, however, the discoloration takes place in irregular patches, giving the stone a mottled appearance.

Blue and gray limestones and dolomites are frequently discolored by irregular efflorescent patches of calcium or magnesium sulphate. These soluble salts are usually brought to the surface by interstitial water. This white efflorescense is not characteristic of the dark colored rocks, although occasionally observed. When observed on the walls of buildings it is not always due to soluble constituents in the rock, but sometimes to the composition of the mortar or cement used in the construction of the walls.

Dark colored rocks, such as red or brown sandstone, seldom discolor, although, after long exposure to the weather, they frequently take on a lighter tint, through the loss of iron oxide, which is washed off from the surface by rain. Decoloration also occurs in the case of some of the granites. It takes place so slowly, however, that it is seldom an important consideration.

The accretion of smut and dust from the atmosphere is one of the chief sources of discoloration of light colored stone used in large cities. A stone which is roughly dressed, furnishes a multitude of places for the lodgment of dust and dirt, while one which is smooth is freer from such places. For this reason a smooth dressed stone is less liable to discolor

by dust and dirt than one which is rough dressed. One must remember, however, that blemishes in the original color of the stone are strongly emphasized by smooth dressing and obscured by rough dressing. These blemishes in the original color may be more unsightly than the dirt and dust, in which case it will be preferable to have the stone rough dressed. The color of the stone depends in a measure upon the manner in which it is dressed. This is especially true of the igneous rocks, variegated marble and some limestone. The color of a stone is best brought out by polishing. Hammer dressing obscures the color and is used to develop contrast with the polished surfaces.

Stone which is used for interior decorations suffers very little from atmospheric agencies and ordinarily the color will remain permanent. The color of the stone used for interior decorations is mainly a question of taste.

The predominant color of stone used for building is controlled in some measure by fashion. A number of years ago, business blocks and residences were largely constructed out of brownstone. At the present time, great quantities of light colored stone are being used and very little brownstone. This is not due so much to the inferior quality of the brownstone as it is to the fact that people have become wearied of gazing at sombre colored buildings. The monotony in architecture would be very greatly relieved by a judicious use of both colors. People dislike the sombre character of long rows of dark colored buildings as well as the dazzling glare of white limestone and marble.

In the construction of business blocks in our large cities the question of color or permanence of color is scarcely worthy of serious consideration. In the midst of the business portion of a great city, white limestone and marble soon lose their original color, becoming gray and dingy from smoke and dirt. Limestone which chances to be bituminious or contains a small amount of petroleum, catches and retains all the dust and smoke which falls upon it. Most of the buildings in the business section of our large cities eventually become so discolored with smoke and dust that one is sometimes at a loss to know whether the stone was originally dark or light colored. On the whole, dark colored stone is preferable in a smoke and dust laden atmosphere. However, it is thought that the chief consideration in the selection of stone to be used in the business portion of a large city should be strength and durability.

In rural districts, or in residence and suburban parts of the city, where there is little smoke or dust, a judicious scattering of light and dark colored stone buildings will add very materially both to the appearance of the street and to the beauty of the individual dwellings. In a

clear atmosphere the color of a stone will change very little from external causes alone.

In the selection of stone for monuments, the taste of the purchaser is the main controlling factor in the color selected. Granite and marble are the principal stones used for monuments and as a rule contain very few minerals which will result in discoloration. Discoloration is mainly brought about through decomposition of pyrite or marcasite. Stones containing either of these minerals are liable to suffer discoloration when exposed to the atmosphere.

In the selection of stone for road making, sidewalks, retaining walls, cribs, breakwaters, bridge abutments, etc., durability and not color should be the controlling factor. In the case of retaining walls and sidewalks, color should receive some consideration owing to the fact that these constructions are party ornamental.

INHERENT QUALITIES OF STONE.

The capacity which a stone has to withstand the forces tending to destroy it is broadly known as durability. Under durability, as used in this broad sense, must be included the strength, hardness, elasticity and stability of the mineral compound. The durability of a stone would then depend upon its mineralogical composition and the texture or state of aggregation of the mineral constituents. By mineralogical composition is meant the kinds of minerals of which the rock is composed and their relative abundance. Texture has reference to the size, shape, manner of contact and arrangement of the mineral particles. The various structures in rocks depend in a measure upon the arrangement of the mineral particles. The effect of alternating heat and cold and the effect of acids depend both upon the mineralogical composition and texture. As ordinarily defined, the specific gravity depends upon the mineralogical composition; the porosity upon the texture; and the weight per cubic foot upon the specific gravity and porosity.

From the above it may be seen that an intimate knowledge of the mineralogical composition and the texture of a rock will give one, who is experienced in these matters, a very good idea of the quality of the stone.

MINERALOGICAL COMPOSITION.

The ordinary building and ornamental stones, including limestone, marble, sandstone, slate, granite and rhyolite, are composed mainly of one or more of the following well known minerals, namely, quartz, feldspar, mica, calcite, dolomite, kaolin, pyroxene, amphibole and serpentine. The relative hardness of these minerals is known and is expressed

by numbers referring to a scale of hardness recognized by all geologists. These minerals have a hardness respectively of 7, 6, 2-3, 3.5-4, 1, 5-6, 5-6, 3-4. It would be interesting to know the crushing strength, tensile strength and co-efficient of elasticity of these minerals. These constants may have been determined, although thus far any attempt to obtain them has been unsuccessful. It is hoped that, before the completion of this report, experiments may be performed in this Bureau through which these constants may be determined. It is also desirable that we know the heat co-efficient of expansion of each of these minerals in order to discuss intelligently the effect of alternating temperatures. The following are the co-efficients of cubical expansion for several of the common rock forming minerals, as given in Clarke's "Constants of Nature," Smithsonian Miscellaneous Collection, Vol. XIV.:

Quartz	.000036	Expansion is different along different axes.
Orthoclase	.000017	
Adularia	.0000179	
Hornblende	.0000284	
Beryl	.000001	
Tourmaline	.000022	
Garnet	.000025	
Calcite	.00002	
Dolomite	.000035	

Quartz is perhaps the commonest and most important of the rock forming minerals. It is the hardest but may not be the strongest or most elastic. There is no well developed cleavage, and under ordinary conditions of temperature and pressure, it is little, if at all, acted upon by common acids. When occurring alone or in crystal aggregates the individuals often have perfect crystal faces, but as a rock making constituent, it occurs in the form of grains which have round, oval, or irregular outlines.

Sandstone and quartzite are composed of from 75 to 98 per cent. of quartz. In granite, rhyolite and gneiss, quartz is a very prominent constituent. Rocks which do not contain more or less quartz are very exceptional.

Quartz is the most permanent of all the rock forming minerals. It is very hard and resists to a very high degree any attempt to break or crush it. As a result of weathering it is often broken into small particles and thus removed from the parent rock, but it is decomposed and taken into solution very slowly.

Feldspar is another very abundant mineral, which is especially characteristic of the igneous rocks. It is slightly softer than quartz and has ready cleavages in two directions. It is very little acted upon by the common acids under ordinary conditions of heat and pressure. Feldspar decomposes very slowly in the quarry, but owing to the great age of

some of the granite and other rocks in which it occurs, it is frequently in an advanced stage of alteration. Owing to the perfect cleavages which it possesses, it disintegrates more readily than quartz. The decomposed products of feldspar are objectionable only in so far as they are more readily disintegrated.

Mica is a very abundant mineral, occurring most frequently in the altered rocks known as metamorphic. It has a very ready cleavage by which it splits into very thin plates. These parting planes provide an easy passage for water, facilitating disintegration which generally proceeds more rapidly than in the case of the quartz and feldspar described above. Where Mica is present in small isolated flakes, uniformily disseminated through the rock, it can scarcely effect the strength or durability of the stone. However, where these flakes are arranged in layers, along the planes of sedimentation, they give the stone a capacity to part, which will necessarily weaken it. The mica, unless it occurs in large individuals or flakes clustered together, will disintegrate scarcely less rapidly than quartz or feldspar. Mica decomposes very slowly through chemical agencies.

Calcite. Calcite is almost as abundant a rock forming constituent as quartz, although it is less permanent at the surface of the earth. The hardness and probably the strength and durability of calcite are all less than quartz. It possesses perfect cleavages in three directions on account of which it disintegrates quite readily. It is easily soluble in carbonated waters and is readily acted upon by cold dilute hydrochloric acid. Calcite is an essential constituent of all limestones, marbles and many sandstones. It also enters into the composition of many of the igneous rocks, being frequently an alteration product of other minerals.

Dolomite differs from calcite, mainly in having a somewhat greater hardness and in the fact that it dissolves less readily in cold dilute hydrochloric acid. It disintegrates almost as readily as calcite, although taken into solution somewhat more slowly. It is one of the most abundant constituents of magnesian limestone, frequently composing as much as 95 per cent. of the rock.

Kaolin is an abundant constituent of slate and a lesser constituent of sandstone, limestone and altered rocks of the granitic type. It is mainly of secondary origin, being usually a decomposition product of feldspar. It is one of the softest minerals, has a perfect cleavage and disintegrates readily. It is not acted upon by the common acids except under very favorable conditions.

Pyroxene is one of the less important minerals of building stone. It occurs mainly in the granites and allied igneous rocks. It cleaves perfectly in two directions and disintegrates slowly through mechanical

abrasion. It gradually decomposes in the presence of water altering to chlorite, calcite and epidote.

Amphibole is an essential constituent of many granites, but is most abundant in the basic igneous rocks. It also occurs in many schists and altered sedimentaries. Under ordinary conditions, at the surface of the earth, it decomposes very slowly.

Serpentine occurs in certain green colored rocks such as verde antique, and is usually an alteration product of olivine. Under ordinary conditions it is a stable chemical compound, but owing to the irregular cracks which it contains, it is seldom used in places exposed to the atmosphere.

Among the accessory minerals common to building stones may be mentioned pyrite, marcasite, hematite, magnetite, graphite and bitumen. Hematite and magnetite are not considered harmful constituents. The red, brown or yellow color of stone is usually attributable to the presence of these constituents. Graphite frequently occurs in limestones, marbles and sandstones and is not an objectionable constituent, except where it occurs in large quantities. Bitumen occurs mainly in limestones and sandstones and is objectionable chiefly on account of the discoloration which is apt to result from the accumulation of dust and dirt from the atmosphere.

Pyrite and marcasite decompose quite readily in the presence of moisture, resulting in the production of yellow iron oxide which, in the case of light colored stone, is apt to result in objectionable forms of discoloration. The decomposition of pyrite in limestone or dolomite also results in the production of magnesium and calcium sulphates which are brought to the surface and deposited in the form of a white efflorescence.

The shattering of rock when subject to high temperatures has been attributed in certain cases to the occurrence of gaseous inclusions in the minerals. To what extent such inclusions assist in the destruction of rock when subjected to a high temperature is not known. It is probable, however, that a temperature which would make these gases active agents of disintegration would destroy the rock through the unequal expansion of the mineral particles.

A stone is an aggregate of minerals and the hardness, strength, elasticity and capacity to withstand chemical action and alternating temperatures are in part controlled by the relative abundance of the different mineral constituents. Provided the size, shape and arrangement of the individuals are constant, the hardness of a stone will increase or decrease with the precentage of quartz which it contains. So in the case of the strength and elasticity of a stone, it will increase as the minerals in which these properties are best developed are increased.

It must be understood, however, that the hardness, compressive strength and elasticity in any mineral may not occupy the same relative position as in other associated minerals. An increase in the percentage of one mineral may increase the hardness of the rock at the expense of strength and elasticity, and vice versa. Finally it must be borne in mind that elasticity, hardness and strength are not controlled entirely by the relative abundance of the different mineral constituents. The size, manner of contact and arrangement of the mineral particles are important factors in determining the qualities of any stone.

TEXTURE OR STATE OF AGGREGATION.

In speaking of the texture of a rock, one has reference to the size, shape, manner of contact and arrangement of the mineral particles. Upon the arrangement of the mineral particles, also depend certain structures in the rock.

The size of the particles affects the manner in which the stone weathers. In case the mineral particles are large, those that are soft disintegrate most readily, often leaving small depressions which give the surface a pitted appearance. Cleavage cracks are more liable to open up in the large than in the small minerals, thereby hastening decomposition. Fine grained rocks may have correspondingly small pore spaces, although the size of the pores is mainly controlled by the shape and manner of contact of the grains.

The shape and manner of contact of the mineral particles influence the strength and durability of the stone as much, if not more, than any of its other qualities. In a stone in which the grains are close fitting, adhesion is increased and the pore space decreased. Grains having irregular outlines usually interlock in the manner of dove-tailing, increasing the strength and lessening the pore space. Upon the arrangement of the grains depend the laminated, schistose or cleavage structures in rocks. The capacity which a rock has to part more readily in one direction than in another, is frequently due to the arrangement of mica or other minerals, having their longer axes in a common direction. The perfection of the parting capacity is influenced by the abundance and size of the grains which have thus arranged themselves.

The percentage of pore space and the size of the pores are controlled by the size, shape, manner of contact and arrangement of the grains. This applies to both igneous and sedimentary rocks, in the latter of which the particles of cement binding the original grains together are considered as grains. The openings in rocks have been divided into three classes. The first are the small interspaces that exist between the

grains of a rock, known as pore spaces; the second are those openings which form along bedding, jointing and fissile planes, known as sheet openings; the third are those openings which have resulted from the removal of several or many individual grains and are commonly known as cavities, caves or caverns.

Pores differ very greatly in size, depending upon the size and shape of the original particles composing the rock, and the extent to which the interstices have been filled with secondary material. These pores are conceived of as being connected in such a manner as to allow water to flow from one part of the formation to another. The pores in a rock are not all of the same size, although they may have a general uniformity in size. Pore spaces in rocks have been classified according to size into super-capillary, capillary and sub-capillary.* The water which fills the capillary pores is known as the water of saturation. Openings of this class are over .00002 centimeter in diameter. Sub-capillary pores are conceived to be of such a size, smaller than .00002 centimeter in diameter, as to contain only the water of imbibition. If a rock containing capillary pores is allowed to drain off naturally, a part of the water will escape, but another portion will remain adhering to the grains. This is known as the water of imbibition. Many rocks contain pores both of capillary and sub-capillary size. In fact, it is thought that there are few building stones which do not contain some pores of sub-capillary size.

As in the case of pores, Van Hise has classified sheet openings which occur along jointing, bedding or other fissile planes as capillary and sub-capillary, including in the latter all such as are less than .00001 centimeter in thickness. The openings of the third and last class, comprising caves, cavities and caverns, occur mainly in limestone and dolomite. They also occur infrequently in rocks which are less readily soluble.

EXTERNAL CAUSES OF DECAY.

It is very important in the selection of a stone to know the climatic conditions under which it is to be placed when in use. A climate which is subject to rapid changes in temperature, or one in which the atmosphere is moist or humid, promotes decay. A climate in which the temperature is uniform and always above the freezing point, and one in which the atmosphere is dry, is conducive of permanence and stability. It requires a stone of the most enduring qualities to withstand the changes of a moist temperate climate, in which there are long seasons of alternate freezing and thawing, short hot summers and cold winters. It is

*"Metamorphism of rocks and rock flowage," C. R. VanHise, Bulletin of the Geological Society of America, Vol. 9, p. 272.

not the inherent qualities of the stone, so much as the warm dry atmosphere, to which the excellent condition of the monuments of Rome and Egypt is attributable. These monuments, after centuries of exposure, are still in an excellent state of preservation. After only forty years of exposure in Paris, the obelisk of Luxor which stood for centuries in Egypt without any perceptible deterioration, is now filled with small cracks and blanched.* The same is true of the obelisk in Central Park, New York, from which many pounds of small fragments have fallen.**

Apparently some stone which has remained unchanged under certain climatic conditions in the quarry, when removed and used under different climatic conditions will deteriorate. Stone is not as sensitive to the atmospheric and climatic changes as man, yet in a measure stone seems to endure best in its native climate. The minerals seem to adjust themselves, in some way, to certain conditions and when removed the stone will deteriorate through the attempt at readjustment.

Changes in a rock are brought about in two ways. First, mechanically, by disintegration, and second, chemically by decomposition. Mechanical disintegration refers to the crumbling of the rock into sand or powder. This may be brought about through chemical changes, but it is usually a result of friction or pressure, by which the adhesion between the particles or the cohesion within the particles is overcome. Decomposition implies a chemical change, through which the identity of the mineral substance is lost. When decomposition takes place, the mineral particles are destroyed by being broken up into other compounds.

The following is a brief classification of the important agents of disintegration and decomposition:

I. AGENTS OF DISINTEGRATION.

A. *Temperature Changes.*
   1. Unequal expansion and contraction of the rock and its mineral constituents.
   2. Expansion occasioned by the alternate freezing and thawing of water contained in the stone.

B. *Abrasion.*
   1. Water.
   2. Wind.
   3. Feet.

C. *Growing Organisms.*

D. *Careless Methods of Working and Handling Stone.*

*A. A. Julien, 10th Census, Vol. V., p. 370.

**Referred to J. C. Smock, Bulletin New York Museum, Vol. II, No. 10, p. 385.

II. AGENTS OF DECOMPOSITION.

A. *Water-Solvent Action.*
B. *Carbon Dioxide.*
C. *Sulphurous Acids.*
D. *Organic Acids.*

AGENTS OF DISINTEGRATION.

Temperature Changes.—Through changes in temperature a stone may be injured in two ways,—first, by the unequal expansion and contraction of the rock and its mineral constituents, and second, through expansion due to the alternate freezing and thawing of the water contained in the stone.

Unequal Expansion and Contraction of the Rock and Its Mineral Constituents.—Stone has a very low heat conductivity. A slab a few inches in thickness may be heated on one side to a temperature so high that it will not bear handling, while the other side of the stone may be comparatively cold. Mr. W. H. Bartlett* has determined experimentally the exact expansion of different kinds of stone. The following are the results which he obtained:

Granite, .000004825 inch per inch for each degree F.
Marble, .000005668 inch per inch for each degree F.
Sandstone, .000009532 inch per inch for each degree F.

In this latitude the diurnal changes in temperature are often as much as 50° Fahrenheit. The annual variation exceeds 100° Fahrenheit. A difference of 100° Fahrenheit would make a difference of about six-tenths of an inch in a sheet of granite 100 feet in diameter.

The difference in the rate of expansion of the different minerals initiates stresses in rocks having a heterogeneous composition, which tend to separate the individual minerals from one another. Whenever a stone is heated, each particle presses against its neighbors with unequal stresses in different directions. When it is cooled, stresses are set up which have a tendency to pull the individual apart. As a result of this expansion and contraction, the rock is weakened and in time small cracks are often produced into which water may percolate or roots descend.

Between the different laminae or hypothetical layers of rock, which are near enough to the surface to be affected by the atmosphere, there is an unequal expansion and contraction. The layer nearest the surface suffers the greatest changes in temperature, while each succeeding layer is less affected. Finally a point is reached where the rock, the year

*Refer to American Journal of Science, Vol. XXII, 1832, p. 136.

around, is not affected by the temperature conditions at the surface. In some regions owing to the rapid changes in temperature, forces are continually at work tending to separate the surface layer from that immediately underneath it. Owing to their heterogeneous mineralogical composition and the interlocking character and difference in size of the grains the igneous rocks are more liable to injury from diurnal changes of temperature than are the sedimentaries.

Geo. P. Merrill* cites an instance in Montana where he found "Along the slopes and valley bottoms, numerous fresh concave and convex chips of andesitic rock which were so abundant and widespread as to be accounted for only by the diurnal temperature changes. During the day the rocks became so highly heated as to become uncomfortable to the touch, while at night the temperature fell nearly to the freezing point." Livingston reports that the temperature of the rock surfaces in Africa frequently rises as high as 137° Fahrenheit. During the night time, the rocks cool off so rapidly as to split off fragments weighing as much as 200 pounds.

The effects of exposure to the weather upon stone in the walls of buildings exposed to the direct rays of the sun, may be observed in most large cities.** The disintegration observed in these places may be best accounted for by the diurnal temperature changes. The movements due to temperature changes are necessarily small, but when they continue through centuries of time they must result in the eventual disintegration of the stone.

Expansion Occasioned by the Alternate Freezing and Thawing of the Included Water.—In this latitude the effect of the alternate freezing and thawing of a rock saturated with water is much greater than that of diurnal temperature changes. Geikie has graphically described the expansive force of freezing water "As being equal to the weight of a column of ice a mile high or a little less than 150 tons to the square foot." In the form of ice at 0° centigrade, one centimeter of water at 0° centigrade occupies 1.0908 centimeters. The damage done through the solidification of confined water is due to this expansion of about one-tenth.

In a consideration of the effects of the freezing and thawing of included water one must clearly distinguish between pores and fissile planes. Openings and hollow spaces are everywhere present in the rock, and through these the water finds its way into the deeper portions of the earth. The water of saturation which is contained in the large pores

* Rock Weathering and Soils, p. 181.

** Rapid changes in temperature frequently result from rain falling on surfaces which are highly heated. This has frequently been known to split stone.

of a rock, is given off with comparative readiness, but that which is contained in the pores or sheet openings of sub-capillary size is retained with very great tenacity. It is easy to understand how the particles composing a rock may be fitted so closely together that these openings will be mainly of sub-capillary size. Most of the water contained in a rock having such pores is the water of imbibition, and will be given off very slowly, increasing the danger from freezing. In general it may be said that the danger from freezing will increase as the pores approach in size those of sub-capillary dimensions. In a non-absorbent rock, there will be vastly greater danger from the freezing of water which has collected in sheet openings owing to the slowness of drainage. Changes in temperature may easily come about before the water has had an opportunity to escape. In a rock containing capillary pores the drainage is much more rapid and the water in the cracks is much more quickly dissipated. A saturated stone which contains large irregular solution cavities and in which the pores are chiefly of sub-capillary size is in very great danger from freezing. The drainage of the water contained in the cavities through the pores is very slow and a sudden change from a thawing to a freezing temperature will prove disastrous.

The pores in two stones, which have a capacity to absorb equal amounts of water, may be very different in size. The stone in which the pores are minute will be in much greater danger from alternate freezing and thawing than the one in which the pores are large. In equally saturated rocks, having pores of the same size, the one having the greater percentage of pore space will be in the greatest danger from alternate freezing and thawing. The effect of freezing will also be conditioned by the percentage of the pore space that is filled with water. A rock which is two-thirds saturated will suffer greater injury from freezing than one which is only one-third saturated. If none of the pores are more than nine-tenths filled with water, there will be no danger from freezing, because the increased bulk resulting from solidification will no more than fill the spaces between the grains.

The amount of water which the pores contain at a given time depends (1) upon the amount of water initially absorbed; (2) the time that has elapsed since the water was absorbed; (3) the size of the pores; (4) the position of the stone; and (5) the condition of the atmosphere. Only in exceptional cases is the stone in the walls of a building saturated. If the pores are of capillary size, the water of saturation will, as a rule, be quickly removed except below the water line.

From the above it appears that in estimating the danger from freezing and thawing, the size of the pore spaces demands first consideration, because this controls the rate at which the interstitial water is

given up. The next important consideration is the amount of water contained in each of the pores at the time of freezing. The third and least important consideration is the total amount of pore space.

T. S. Hunt in "Chemical and geological essays," says: "Other things being equal, it may properly be said that the value of a stone for building purposes is inversely as its porosity or absorbing power." Various authorities have quoted this statement saying in general: "Other things being equal, the more porous the stone the greater the danger from frost." A common mistake is to estimate the danger of freezing from the capacity which a stone has to absorb water. The durability of a stone is constantly being estimated from its ratio of absorption. Unfortunately these estimates are very misleading. Although one should know the capacity which a stone has to absorb water, in making an estimate of durability, he should give first consideration to the size of the pores.

Quarrymen and contractors are familiar with the injurious effects of the freezing of the interstitial water known as "quarry water." Contractors frequently refuse to accept stone, especially sandstone, which has not been seasoned before being exposed to the action of frost. Quarrymen sometimes flood their quarries during the winter months that the stone immediately at the surface may be protected.

Bedding, jointing and other fissile planes permit a freer circulation of water than the pores in the rock. The water from rain and melting snow, which collects in cracks, crevices and pores at or near the surface is carried away much more slowly than it accumulates. In case the temperature is fluctuating between freezing and thawing, the water in these crevices will be alternately in a liquid and solid state. As the water freezes and melts again and again, the walls of the cracks are shoved farther and farther apart. The ice acts as a wedge, which automatically adjusts itself to the size of the crack, until the opening is sufficiently wide and deep to permit a free passage of the water. Besides enlarging and extending the cracks and crevices, the freezing of the water exerts a pressure, on account of which the stone is itself materially weakened.

One must not confuse the danger from the freezing of water which collects along parting planes with the danger attendant upon the freezing of water which fills the pores. Rocks, in which bedding, jointing and other fissile planes occur, are in greater danger from alternate freezing and thawing than the compact thoroughly homogeneous rocks which have no bedding or other parting planes.

One of the chief causes of the deterioration of building stone, and more especially stone which is bedded or otherwise laminated, is the

alternate freezing and thawing of the included water. The use of stone which is laid on edge instead of on the bed, and that which has not been properly seasoned, has frequently been accompanied by disastrous results. Stone which is frozen before being properly seasoned is weakened throughout its mass, while that which is laid on edge frequently deteriorates through exfoliation or scaling. The most dangerous place for a stone in a building is at the water line, where saturation is most common and alternate freezing and thawing most frequent. In the case of bridge abutments and retaining walls, the conditions are even more severe than at the water line in a foundation wall. The courses of stone at the water level in bridge abutments are frequently badly shelled and broken, while the stone above and below may be entirely uninjured. Retaining walls are frequently in a very dilapidated condition after they have been constructed comparatively few years. The water which seeps into the ground above a retaining wall often issues through cracks and crevices in the stone. Under certain atmospheric conditions the water will freeze as it reaches the surface, forming ice wedges which push the laminae of the rocks apart.

Sedimentary rocks, owing to the frequency with which they have parting planes, are, as a class, more apt to suffer from alternate freezing and thawing than the igneous rocks. Sometimes, however, the sedimentary rocks are as free from parting planes as the igneous, and are accordingly in as little or even less danger from freezing.

Very little attention need be given to caves, caverns and cavities. Cavities are of common occurrence in both sedimentary and igneous rocks, although more abundant in the former. In practice the danger from freezing is not materially increased by their presence, owing to the fact that they are seldom filled with water when near the surface. As the cavities approach capillary pores in size they increase the danger attendant upon freezing, especially if the only means of drainage be through very minute pores. It may be said that cavities are most objectionable when they occur in stone in which the pores are very minute. Cavities weaken the rock slightly and often produce a roughness at the surface.

If the foregoing is accepted, we must conclude that an ordinary well cemented sandstone, which is free from parting planes or stratification, and in which the pores are of capillary size, is best suited to withstand alternate freezing and thawing in the walls of a building; it being assumed that the strength of the stone is sufficient for the position which it occupies.

Mechanical Abrasion.—The comminution of the rocks mechanically, or through abrasion, is one of the most important processes in the wast-

ing away of the land surface. However, the part which it plays in the destruction of buildings and other forms of masonry construction, is not nearly as important as that of other agencies.

Mechanical abrasion is accomplished mainly by wind, running water and the shuffling of feet. The rain which beats against a stone wall may overcome the adhesion between the rock particles, separating them from one another and carrying them away. As these particles are carried down the side of the building, they, in turn, may loosen other particles, and so on until the ground is reached. Drifting sand, which is such an important agent of disintegration in the arid regions, plays a very unimportant part in the temperate zone. It contributes an almost insignificant part to the process of disintegration. Professor J. C. Smock, in his report on the building stones of New York, mentions the fact that the ground glass character of many of the window panes, in some of the older houses of Nantucket, is due to drifting sand. Drifting sand in some of the older eastern cemeteries has removed the polish, and in some cases even the lettering on the monuments.

Stone, which is used for sidewalks, floorings, steps, etc., is in a position where it is subject to the abrading action of feet which are constantly passing over its surface. There is a great difference in the capacity which different stones possess to withstand abrasion. In every city one finds sidewalks and pavements which are badly worn by the constant shuffling of feet over their surfaces. The steps approaching the capitol in Jefferson City are badly worn through this agency.

Growing Organisms.—Stone in the quarries and elsewhere is frequently covered with a growth of lichens and algae. Trees growing on the hillsides often send their roots deep into crevices and cracks and by their growth and expansion break off huge blocks of stone from the parent mass. Occasionally in very soft, porous rocks the writer has observed the finer rootlets, ramifying through the body of the rock itself. Organic acids, produced by the decaying plants, aid in the decomposition of the rock. Lichens often cover the natural rock exposures, forming a mat, which exerts both a protective and destructive influence. They serve to protect the rock from the atmosphere, while the acids formed through their decay and the mechanical action of their rootlets, penetrating between the grains, result in slow disintegration. The damp parts of a wall are frequently covered with green algae, which cause discoloration through their own decay and the accumulation of fine dust particles from the atmosphere. Creeping vines, such as ivy, serve as picturesque coverings to the walls of a building, although they are undoubtedly somewhat harmful to the stone.

Careless Methods of Working and Handling.—The rapidity with which atmospheric agencies cause disintegration is often greatly accelerated through the weakening of a stone by improper methods of quarrying, and carelessness in cutting, carving and laying the stone in the building. Improper methods of quarrying and handling have probably resulted in shortening the life of the stone used in many buildings at least one-half.

Dynamite is sometimes used to move stone in a quarry, from which it is expected to obtain dimension stone for building purposes. Heavy charges of powder not only destroy a large quantity of stone, but they also shatter the cement which binds the particles together and produce incipient joints, which lessen both the strength and durability of the stone. The incipient joints not only weaken the rock, but facilitate the entrance of water, with the attendant dangers from alternate freezing and thawing. This method of quarrying not only lessens the value of the saleable stone, but frequently destroys hundreds of tons of stone which would otherwise be marketable. Splitting stone, by striking continuously along one line with heavy hammers and sledges, injures it in the same manner as heavy blasting.

These injuries to the stone, brought about by quarrying, may be avoided by exercising ordinary care. Quarrymen, as far as possible, should take advantage of the natural joints. Wherever it becomes necessary to use powder, the Knox system of small charges properly distributed, is thought to be the least injurious. In working sandstone and limestone on an extensive scale, the channeling machine is considered the best method of reducing the stone to dimensions that can be easily handled.

During the process of seasoning, the quarry water comes to the surface, evaporates and deposits mineral matter, which frequently forms a crust on the surface of the stone. This crust is usually formed entirely by the evaporation of the original interstitial water. It is thought, that through saturation with water containing the same mineral salts in solution and by subsequent evaporation, an almost appreciable amount of mineral matter may be deposited at the surface, as in the case of the evaporation of the original interstitial water. The water of imbibition which has been defined above, probably carries a much greater percentage of mineral matter in solution than the water of saturation. The water of imbibition is the last of the quarry water to leave the stone and its complete removal will not be accomplished until the rock has been thoroughly seasoned. In case a stone is of such a nature that it must be seasoned before being placed in the wall, it should be first cut, dressed and

carved. When first quarried a stone often works much more readily than after it has been seasoned. For this reason, as well as from the standpoint of their future durability, some stones should be dressed before being placed in a wall. After the crust has once formed, it should not be broken, because the softer rock underneath, when exposed at the surface, will disintegrate much more rapidly. It is evident from these observations that the time of cutting and dressing a stone may influence its life to such an extent, as to make it important that it should be finished, ready for laying in the wall, before being thoroughly seasoned.

The life of a stone is also influenced in a small way by the manner of dressing. A polished surface sheds water more quickly than a rough one. A stone with rough surfaces has many crannies and crevices in which the water may collect, and from which it may be absorbed. Hammer dressed sandstone is liable to disintegrate faster at first than that which has been sawed, due to a weakening of the cement by the impact of the hammer. Polished and sawn surfaces, as a rule, shed water more readily than those that are hammer dressed. The rock faced and hammer dressed blocks, on account of their rough exterior, absorb a considerably larger percentage of the water which falls on their surfaces, than the polished and rubbed surfaces.

The exfoliation of sandstone has been attributed mainly to the laying of stone on edge instead of on the bed. Owing to the greater readiness with which stratified and schistose rocks can be dressed along the bed, they are frequently laid on edge. This has been practiced more especially in veneer work, but is occasionally met with in heavy masonry. Where the parting planes are normal or inclined to the surface of the earth, they admit the passage of water more readily than where they are parallel. If a block of stone is laid on edge in a wall, the danger from freezing of the included water is greater than if it were laid on the bed. The pressure required to split off laminae of stone which is laid on edge, is ordinarily much less than in case of stone which is laid on the bed. The force occasioned by the freezing of water, which collects between the layers, is augmented by the superincumbent pressure of the wall. Water is less apt to penetrate along the parting planes in case the stone is laid on its bed, and even though it should penetrate with equal freedom in this position, the superincumbent pressure of the wall would tend to force the expansion in directions of least resistance, which are parallel to the bedding.

In case the stone is laid on edge, the different blocks will emphasize more strikingly the differences in the texture than if it were laid on the bed. The different blocks will, as a whole, exhibit different rates

of wear, instead of the minor inequalities usually shown by the different laminae when the block is laid on the bed. The only safe rule to follow, in important structures, is to avoid laying any stone on edge which shows stratification or schistosity. In this position the stone is usually weaker, promotes a more ready absorption of water, and is in greater danger from alternate freezing and thawing.

AGENTS OF DECOMPOSITION.

In buildings, the decomposition of stone proceeds much more slowly than disintegration. The work of breaking down the chemical compounds is a much greater task than simply overcoming adhesion and cohesion.

Water.—Water is the most active agent in producing chemical changes in rock. It generally contains, besides mineral salts, either sulphuric, sulphurous, carbonic or organic acids, in solution. Thereby the water is often a very dilute acid solution. As it percolates through the rock, small quantities of mineral matter are taken into solution in one place, and precipitated or deposited in another. In this way, the minerals, of which both the igneous and sedimentary rocks are composed, are broken down and large quantities of the mineral substances are transferred from one place to another.

The chemical decomposition of minerals in building stone is so slow that it seldom affects the life of the stone after it is placed in a building. Limestone, dolomite, marble and other rocks, in which iron sulphide or iron carbonate occur, are the only building stones which show any appreciable deterioration through the decomposition of their mineral constituents.

Sulphurous Acid.—The most conspicuous case of mineral decomposition is that of iron sulphide, which breaks down in the presence of water, forming iron oxide and sulphurous and sulphuric acids. In the case of dolomite, these acids act upon the magnesium carbonate producing magnesium sulphate, which is frequently brought to the surface and deposited as an efflorescence or incrustation.

In cities, where the consumption of bituminous coal is large, sulphurous and sulphuric acids are usually present in the atmosphere in considerable quantities. The effect of these acids increases where the atmosphere is moist. In London where the consumption of soft coal is very large and fogs predominate, there seems to be little question but that the effect of these gases is worthy of careful consideration. In the United States, with the exception of a few large cities, these agents have comparatively little influence.

Carbon Dioxide.—Water which holds in solution or is charged with

carbonic acid gas, when passed through calcareous rocks takes into solution more or less of the calcium carbonate. This naturally lessens the adhesion between the different particles and weakens the rock. In nature decomposition from this cause takes place on a very large scale, but in the walls of a building its effect is scarcely appreciable.

Organic Acids.—The organic acids resulting from decaying organisms have little or no affect upon the strength and durability of stone used in the walls of buildings.

CHAPTER III.

THE PROPERTIES OF STONE USED IN BUILDING CONSTRUCTIONS AND METHODS OF DETERMINING THE SAME.

The suitability of a stone for any of the numerous uses to which it may be put, depends mainly upon its color, strength and durability and the condition of the quarry in which it occurs.

The color of a stone depends upon its mineralogical composition; the strength depends chiefly upon the mineralogical composition and texture; and the durability upon the capacity which the stone has to withstand temperature changes and the action of gases and dilute acids. In order to estimate the quality of a stone based upon its strength and durability one usually determines,—

I. Composition { Mineralogical / Chemical.

II. Strength { Crushing / Transverse / Tensile.

III. Hardness.

IV. Elasticity.

V. Porosity.

VI. Presence of fissile planes.

VII. Specific gravity.

VIII. Weight per cubic foot.

IX. Capacity to withstand temperature changes.

(a) Freezing and thawing of included water.

(b) Alternate heating and cooling.

X. Capacity to withstand gases and dilute acids (Carbonic, sulphurous, etc.)

One may obtain these facts by three different methods: (1) by making an examination of the stone in the quarry and adjacent natural exposures; (2) by a careful inspection of buildings and other structures built out of the stone under examination; and (3) by a series of laboratory tests. Which of these methods of determining the durability of

stone is considered most satisfactory, depends upon the individual making the examination. A geologist would probably select a combination of the first and third methods; an engineer would probably select the third; while a layman or an architect would undoubtedly be best satisfied with the second. The value of an opinion based solely upon quarry observations or building inspection, must depend largely upon judgment and experience. They lack the definiteness and certainty which results from a carefully performed series of laboratory tests. However, no one of these should be considered sufficient in itself, but each should be used to supplement the other two.

QUARRY OBSERVATIONS.

In the selection of stone for large buildings, much depends upon the location, condition and equipment of the quarry. These cannot be ascertained by an examination of the building or selected samples in the laboratory, but must be learned from an examination of the quarry. The permanence and uniformity of the color of the stone may also be determined by an examination of the quarry and adjacent exposures.

The mineralogical composition may be determined approximately, while the hardness, strength, weight and porosity may be roughly estimated at the quarry. The manner in which the stone weathers, as shown by the adjacent outcrops, furnishes a basis for a rough estimate of the durability of the stone.

A quarry should be located favorably for transportation. If one is required to haul stone by team for any distance, there is always danger of delay on account of bad roads. A quarry is not suitably equipped for filling large orders for building stone until railroad facilities have been provided at the quarry.

The stone in all parts of the quarry may not be of the same quality. This is frequently the condition in the sedimentary rocks. The stone from one part or from one ledge may be strong and durable, while that in another part, or at another horizon may be unfit for use. It frequently happens that the best stone is deeply buried beneath other beds of inferior quality. The desirable stone is thus made inaccessible, and occasionally the quarryman supplies an inferior stone in place of the better quality. The condition whereby this might happen can only be determined by an examination of the quarry.

It occasionally happens that the desirable stone in a quarry becomes exhausted, although the owners still continue to sell stone on the basis of the earlier conditions in the quarry. Improper methods of quarrying and dressing and careless handling are frequently such as to warrant one in

condemning a stone which otherwise might be desirable. A quarry may be poorly equipped with machinery, men may be scarce, orders for stone may be plentiful and, as a consequence, an inferior product may be marketed. These conditions can best be determined by an examination of the quarry and its equipment.

The uniformity and permanence of the color of stone can be most satisfactorily determined at the quarry. If the color fades rapidly upon exposure to the atmosphere, it will be shown in the weathered outcrops, which can usually be found adjacent to the quarry. If the stone differs in color at different horizons or in different parts of the quarry, a careful inspection will reveal this condition and precautions may be taken to insure the receipt of stone of uniform color, by designating the ledge and even the portion of the quarry from which the stone is to be taken. The weathered outcrops may show the stone to be bleached, stained with brown iron oxide or discolored with white efflorescent patches. The bleaching process ordinarily takes place very slowly and the depth to which it extends indicates, in a measure, the permanence of the coloring matter. Brown staining usually indicates the presence of iron, and white efflorescent patches give evidence of soluble magnesium or calcium salts.

Differences which may exist in the mineralogical composition of a stone can often be determined by an examination of the quarry. One who is familiar with the common rock forming minerals may easily detect differences in the composition and texture of the rock by examining it as it occurs in the quarry.

The strength, hardness, elasticity and porosity of a stone depend upon its mineralogical composition and texture. Therefore, if one is acquainted with the mineralogical composition, as well as the size, shape and manner of contact of the individual grains, he may estimate approximately these qualities, which otherwise must be determined by physical tests in the laboratory. The experienced observer should not only be able to detect differences in the qualities of stone from different parts of the same quarry, but he should also be able to make comparisons of stone from different quarries and districts.

The durability of a stone may be estimated simply by comparing the weathered and fresh exposures in the quarry. Such estimates must be very rough, owing to the uncertain length of time during which the weathered surface has been exposed to the atmosphere. The stone may have been uncovered for centuries, or perhaps for only a few years.

In glaciated regions, the hardness may frequently be estimated from the depth and extent to which the surface has been grooved and striated. Owing to the fact that these markings are controlled in part by the condition of the glaciers, they are sometimes very uncertain evi-

dence from which to estimate the hardness of a rock. The length of time that the surface has been exposed to the atmosphere since glaciation also affects the condition of the striae, making them a less important criterion of the hardness.

Where disintegration and decomposition have not extended to too great a depth, the natural exposures will reveal inequalities in hardness resulting from concretions, nodules, pebbles, clay seams or pockets and fossils.

Structures, such as sedimentary and jointing planes, which may be obscured in the freshly quarried rock, are emphasized by weathering. Quarrymen often contend that joints die out with depth, but this cannot be laid down as a general rule within the superficial zone to which quarrying may profitably extend. Some joints which show at the surface are undoubtedly superficial, but others penetrate to very considerable depths. It is thought that the depth to which joints extend is in a measure proportional to their length.

The durability of a stone may be estimated from the depth to which disintegration and decomposition have extended. The time element, however, enters again to vitiate more or less the conclusions. A luxurious growth of lichens on the exposed surface of the rock is frequently considered an evidence of durability. However, this criterion, when taken alone, has very little significance. Lichens frequently grow in abundance on the surface of sandstone which is inherently soft. In this case, however, they indicate that a crust has been formed on the surface of the stone.

It is very necessary that one should visit a quarry to assure himself that the amount of stone of the desired quality is obtainable. It frequently happens that a quarry becomes exhausted of its good stone and for this reason one should acquaint himself with the conditions at the quarry. On the other hand, quarries which have a high percentage of excellent stone, have frequently been condemned by the public because the quarryman or contractor has permitted the use of a few inferior blocks in conspicuous places. If one wishes to know positively that he is receiving the best stone that a quarry produces, he should be personally acquainted with the possibilities of the quarry.

OBSERVATIONS ON BUILDINGS AND OTHER CONSTRUCTIONS.

The inspection of buildings of long standing has always been recognized as an important means of estimating the strength and durability of stone. The value of such observations, however, is often over esti-

mated because frequently one cannot know how the stone was quarried, handled, dressed or laid.

Any estimate of the strength and durability of a stone made from the examination of a building should take into consideration (1) the age of the building, (2) its size, (3) the climatic or atmospheric conditions, (4) its situation, (5) the grade of stone used and the manner in which the stone was quarried, handled, dressed and laid.

It is worse than folly to estimate the strength and durability of the stone in a building without knowing the age of the building. During the first twenty-five years, a stone may not exhibit any material deterioration, while the next ten or fifteen years may show rapid decay. Very few of the buildings in the United States can be considered old, and the actual disintegration is comparatively little. Many that are fifty or more years old, do not exhibit the first signs of decay. Frequently the actual disintegration is so slight that one must content himself with searching for the beginnings of decay. It is interesting, however, to note that in some instances disintegration has proceeded so rapidly as to render the buildings at the present time unsafe.

The rate of decay may be increased by the height of a building. Apparently the weight of the superstructure assists the atmospheric agents in their work of destruction.

The location of a building, in the business or residence part of a city, protected or exposed to the storms and prevailing winds, will influence more or less the life of a stone Likewise, the location of a building, in an atmosphere which is temperate, torrid, frigid, humid or arid, will affect its permanence. A stone which might remain unchanged for centuries in an arid region will frequently crumble and decay, in a few years, in a moist temperate climate

The grade of stone affects very materially the life of a building. It is not uncommon for the poorer grades of stone to be used in the fronts of buildings or even carved for the finer parts of architectural work. After a stone once becomes a part of a building, people do not stop to distinguish different grades, but attribute the weaknesses or imperfections in the inferior grade of stone to the quarry as a whole. It is not unusual for the stone from an entire district, including several quarries, to be condemned because second or third grade stone has not proven as satisfactory as number one stone from another district.

The manner in which the stone is quarried, handled, dressed and laid is also very important. Much stone is still being laid on edge, especially in veneer work. In case the bedding planes are prominent and the stone is only of moderate strength, this practice is dangerous. A stone which is strong and durable, when laid on the bed, may be weak and imperfect

when laid on edge. One should ascertain if possible whether the flaking and scaling is due to inherent weakness in the stone or to improper methods of laying.

Stone used for ornamental and monumental purposes will show deterioration in proportion to its age, position, etc., the same as stone used in the walls of buildings. The same care should be exercised in passing judgment on its durability as if it were a part of a building.

The oldest monuments in our cemeteries are marble, it being only within a few years that granite has come into very general use. Some of the granite monuments, in spite of the comparatively recent date of their erection, are gradually losing their polish, and even now have very finely pitted surfaces. The lettering is frequently dimmed and the polishing obliterated on monuments that have been exposed a very few years to dust laden winds. The diurnal expansion and contraction, caused by heating and cooling, often result in deterioration on the surfaces exposed to the direct rays of the sun.

The perfection of the polish which a stone will take and the contrast between the hammered and polished surfaces can be best ascertained from the finished work. However, one should not permit the elaborateness or excellence of workmanship to influence the judgment. The polished surfaces are sometimes oiled, giving a brilliancy and lustre which is not inherent in the stone itself. For this reason, a monument should not be finally accepted until it has been exposed to the atmosphere for at least six months.

The strength and durability of stone used for highways can be in a measure estimated by inspecting pavements and sidewalks, which have been constructed out of the materials in question. A just comparison, however, can only be made, when the manner of construction, the amount of traffic, the character of the subsoil, the climatic conditions and the date of construction are known. One may determine from an examination of pavements the durability of the materials and whether or not they become slippery or uneven by wear. These facts, however, can be obtained more accurately and with less trouble by testing the stone in the laboratory.

LABORATORY TESTS.

A knowledge of the mineralogical and chemical compositions and physical properties of a stone, and the climatic and other conditions to which it will be subject when in use, furnish a basis from which one can predict with a remarkable degree of accuracy, without inspecting the quarry or examining buildings of long standing, the results of exposure to the atmosphere. It is not always possible or convenient to have a

stone tested in the laboratory and frequently quarrymen do not seek it. Architects and contractors, however, are always glad to have at their command reliable laboratory tests on stone.

There are three important classes of laboratory tests, namely, (1) chemical, (2) microscopical, and (3) physical.

Chemical.—The only exact method of determining the elements of which a rock is composed is by means of a chemical analysis. This is also the best method of determining the proportions in which the mineral constituents are present. The presence of deleterious constituents, such as ferrous iron, bitumen, etc., and the quantity of each present may be determined in this way. Ordinarily a chemical analysis is the least important of the laboratory tests, but it can be made useful in estimating the durability of a stone in case a microscopical examination is impracticable.

Microscopical.—Much may be learned of the strength and durability of stone through a microscopical examination of thin sections. By the aid of a magnifying glass, one can determine approximately the mineralogical composition and texture of a coarse grained stone.

In the case of a very fine grained rock, the mineralogical composition and texture can only be accurately determined by a microscopical examination of thin sections.

The microscopical examination is not only less expensive, but it is of much greater practical value than a chemical analysis. It is known that the durability of a stone depends upon its mineralogical composition and texture, each of which can be determined with a high degree of accuracy by the use of a microscope. It is possible by aid of the microscope to determine not only the relative abundance of the different minerals, but also the chemical composition. Minerals that are readily decomposed and liable to cause discoloration can be identified, and the presence of cracks, strains and gas bubbles can be detected. It is possible to estimate, with a fair degree of accuracy, the compressive, cross breaking and tensile strength of the stone, from a knowledge of the mineralogical composition and texture combined with a knowledge of the physical properties of the different minerals of which the stone is composed. For this purpose one should have a knowledge of the compressive and cross breaking strength of the different minerals, as well as a knowledge of the proportion in which each of these minerals is present in the rock, the size of the grains, and the manner of contact.

Frequently cracks and strains observed in thin sections are due to stresses, resulting from cutting and grinding. For this reason one should be careful in drawing conclusions from their presence in the sections examined.

The size and abundance of the pore spaces can be estimated from the texture, closeness and manner of contact of the grains. It is thought that one might possibly measure these spaces quantitatively under the microscope by saturating the rock with a colored gelatinous substance which will fill the pores.

All of the characteristics of a rock which contribute to its strength, hardness, elasticity, capacity to withstand alternate heat and cold and freezing and thawing, and the effects of carbonated and acidulated waters, can be approximately determined by an examination of thin sections under the microscope. It is thought that an intelligent interpretation of the facts revealed by the microscope might eventually render the physical tests and chemical analysis unnecessary. At present, however, the microscopic examination of thin sections is only intelligible to the petrographer. He is the only one who can interpret the facts thus observed and the accuracy of his conclusions will depend upon his judgment and experience. With the public, this method may never supplant the physical tests, because it lacks the quantitative element.

Physical Tests.—The purpose of the physical tests is to determine by artificial methods the strength and durability of a stone. On account of careless methods of quarrying, handling, dressing and laying, the decay of stone in buildings is not always evidence of inherent weakness. For this reason the physical tests, obtained in the laboratory, provide a more reliable basis from which to estimate strength and durability.

The strength and elasticity of a stone can both be obtained very easily by preparing cubical and rectangular pieces to be used in testing machines constructed for making these determinations. It is more difficult, however, to express quantitatively the deterioration through atmospheric changes, on account of the practical impossibility of measuring in a few weeks or months, in the laboratory, any deterioration that might take place in years under ordinary climatic conditions. Besides this, the conditions in nature change daily both in intensity and kind and, as a rule, there are several agents of destruction, instead of one, operating at any given time. The effect of these agents in the laboratory must be measured separately and on such a grossly exaggerated scale that there will be accomplished in a brief period that which would require many years in nature.

The following determinations are usually made as a basis for estimates of durability:

I. Strength.
   (a) Compressive, or crushing.
   (b) Transverse.
   (c) Tensile.

II. Elasticity, modulus.
III. Hardness—coefficient of wear.
IV. Specific gravity.
V. Porosity.
VI. Weight per cubic foot.
VII. Capacity to withstand temperature changes.
  (a) Freezing of included water.
  (b) Effect of extreme heat.
VIII. Capacity to withstand gases and dilute acids.
  (a) Carbonic acid.
  (b) Sulphurous acid.

In a former report, an attempt was made to classify the tests under "strength tests" and "durability tests." Such a classification is thought to be illogical, because some of the tests have a double significance, indicating both strength and durability.

STRENGTH.

Heretofore it has been customary to determine chiefly the compressive strength of building stones. It is thought to be important, however, that one should be familiar with the compressive, tensile and cross breaking strength, as shown by the crushing, cross breaking and tensile strength tests.

Crushing Strength.—Up to within a few years the durability of a stone has been estimated mainly from the crushing or ultimate strength as determined by the compressive strength test. However, a stone having a low crushing strength may be more durable than one in which the crushing strength is high. For this reason this test is not sufficient for estimating the durability of a stone. The absence of other tests has probably been the cause for frequently overestimating the importance of the crushing strength. On the other hand, it is argued by some that the determination of the crushing strength, except in doubtful cases, is entirely unnecessary. Although this may be in a measure true, I do not consider it wise to encourage the abandonment of the crushing strength test. Architects are very glad to avail themselves of all information giving the crushing strength of stone which they have under consideration for use in buildings. The only intelligible method of expressing the strength of a stone, to one not familiar with the interpretation of the mineralogical composition and texture, is in pounds per square inch.

The crushing strength is useful in estimating the durability of a stone, as well as having an important scientific bearing upon problems in dynamic geology.

In very large buildings, single columns or blocks are often required to carry very heavy loads. They frequently support bridge trusses and other constructions of equal weight. It is important to know, approximately, the crushing strength of a stone which is to be used for these purposes.

In ordinary buildings, the lower courses of stone are not required to carry a very heavy weight of superstructure. It has been computed that the stone at the base of Washington's monument sustains a maximum pressure of 22.658 tons per square foot, or 314.6 pounds per square inch. A stone is usually required to withstand twenty times the pressure to which it will be subject when placed in a wall. This factor of safety, however, would require for stone at the base of this monument, a crushing strength of only 6,292 pounds per square inch. The pressure at the base of the tallest buildings in this country can scarcely exceed one half of that at the base of this monument, or 157.3 pounds per square inch. In such positions, with a factor of safety of twenty, the stone would not be required to have a crushing strength of more than 3,146 pounds per square inch. There are very few building stones in the country that do not have a crushing strength higher than this. It may happen, however, that as the result of an unequal distribution of the load, certain stones in the wall or columns will be called upon to sustain twenty or even fifty times their proportion of the load, in which case the crushing strength should be much greater. In general, however, a crushing strength of 5,000 pounds per square inch is considered sufficient for all ordinary building constructions.

The crushing strength of a stone is obtained by breaking 2-inch cubes in a testing machine constructed for this purpose. These cubes can be prepared in any laboratory, which is provided with appliances for cutting and dressing stone. The cubes should be of uniform size and very carefully sawed from a stone block which has not been injured by rough handling or hammer dressing. The faces should be rubbed smooth and the opposite sides should be perfectly parallel. Smaller or larger cubes may be used, although some authors still maintain that the crushing strength per unit of area varies with the size of the cube tested. General Gilmore at one time constructed an empirical formula for reducing all tests to pounds per square inch on 2-inch cubes. It has been shown, however, that this formula is neither theoretically nor practically true. It is the almost general belief now that the crushing strength per square inch does not vary with the size of the cubes nor with their cubical or prismatic shape. This question, however, is not settled to the satisfaction of all, and until it is, it is thought best that all tests be made on 2-inch cubes.

Before making the tests the stone should be thoroughly dried and the average area of the bearing faces determined. To assist in distributing the load and to take up any unevenness in the bearing faces, thin strips of blotting paper, wood, lead or plaster of paris are often placed between the steel plates of the machine and the bearing faces of the stone cubes. It is claimed by some, however, that this has a tendency to lower the crushing strength of the stone. If the cubes have been carefully prepared, this will be unnecessary, and the author believes that, for the sake of uniformity, it would be best to apply the bearing faces directly to the steel plates of the machine, a spherical compression block being used in making the test. A record should be kept of the direction in which the pressure is applied with respect to bedding. The crushing strength per square inch is computed by dividing the ultimate strength of the block by the average area of the bearing surfaces in square inches. One should note carefully the load at which the cubes are first cracked, the ultimate strength, the perfection of the resulting pyramids and the explosive manner in which the cubes may break.

While conducting a series of tests in the preparation of another report on "Building Stones" it was ascertained that stone when subjected to compressive stresses, much below its ultimate strength—either continuously or intermittently—would weaken. In a subsequent chapter will be found a series of tests illustrating this phenomenon which is known as "fatigue in stone." This is the first attempt which has yet been made to show this property in stone and the importance of the results cannot, at this time, be estimated.

Transverse Strength.—The force required to break a bar of any material one inch square when resting on supports one inch apart, the load being applied in the middle, is known as the transverse strength, which is measured in terms of the modulus of rupture. The importance of this determination has not been fully recognized, if one should judge from the data available The need of a more general appreciation of the value of this test is apparent to any one who has observed the broken caps and sills in many of the larger buildings in this country. Frequently one finds a stone that has such a low modulus of rupture as to be unfit for use in a position where only a moderate transverse strength is required.

The thickness of a sill or cap depends mainly upon the transverse strength of the stone. The danger from weak stone and unequal stresses is often so great that doors and windows are arched instead of being capped with a single stone.

The pieces used for determining the modulus of rupture should be prepared by sawing and should have a cross section of one square inch and

a length of from 6 to 8 inches. The sides should be smooth and the opposite ones parallel. The pieces thus prepared should be placed in a testing machine in which both ends are supported on knife edges and the pressure applied in the middle. The weight required to break the sample and the place where the rupture occurs should be carefully noted. The modulus of rupture may be computed from the following formula:

$$W = \frac{2\,bd^2}{3\,L} R \text{ from which}$$

$$R = \frac{3\,L}{2\,bd^2} W.$$

W = concentrated load at center in pounds.
B = breadth in inches.
D = depth in inches.
L = length.
R = modulus of rupture in pounds per square inch.

Tensile Strength.—Up to the present time apparently no one has endeavored to determine directly the tensile strength of stone of any kind. This can be obtained by preparing pieces similar to those used for determining the tensile strength of cement. They are made carefully by sawing and rubbing, in order to avoid any possible injury that might be occasioned by using a hammer and chisel. The briquettes are made so that the weakest section is at the center and this has a 1-inch cross section.

Before testing, the briquettes are carefully dried and the bearing surfaces are made parallel, so that the line of contact with the clips are nearly perfect. The briquettes are properly centered in the clips so that the test piece adjusts itself to an even bearing.

Tensile strength tests of this character may be made in the Michaelis, Fairbanks, Riehle or Olson testing machines. The tests referred to in this report were made in an Olson machine.

Modulus of Elasticity.—The modulus of elasticity is synonymous with coefficient of elasticity, and is sometimes defined as the weight that would be required to stretch a rod one square inch in cross section to double its length. The result is usually expressed in pounds per square inch. It is "valuable in determining the effect of combining masonry and metal; of joining different kinds of masonry or of joining new masonry to old; in calculating the effect of loading a masonry arch; in proportioning abutments and piers of railroad bridges subject to shock, etc." (Baker). One method of measuring the modulus of elasticity is by recording the amount of compression which a 2-inch cube of stone

undergoes for each increment of 500 to 1,000 pounds load to the limit of elasticity. From the data thus obtained, the modulus of elasticity may be computed by the use of an empirical formula. The value of this determination from a commercial standpoint is somewhat doubtful, owing to the fact that it is seldom referred to by architects. One reason for their not being used is probably due to the comparatively few tests which have been made.

Hardness.—Wherever in masonry construction a stone is subjected to abrasion, it is desirable to know its hardness. This can be determined quantitatively by the use of the abrading machine. The results of this test are expressed as the coefficient of wear. The Duval abrading machine is the one most commonly used to determine the wearing qualities of stone to be used in macadam pavements. This "consists of four cylinders, each twenty centimeters in diameter and thirty-four centimeters in depth. Each of these cylinders is closed at one end and has a tightly fitting cover for the other. They are fastened to a shaft so that the axis of each cylinder is at an angle of 30° with the axis of rotation of the shaft. The shaft which holds the cylinder is supported by bearings, and at one of its ends is a pulley by which the cylinders are revolved, at the other a revolution counter."*

In performing this test no stone whose greatest dimensions is more than 2½ inches or less than 2 inches is used. Five kilograms of the stone are used in making the test. After the sample is weighed it is placed in a cylinder and the cover bolted on. When a sample has been placed in each of the cylinders, they are revolved at the rate of about 2,000 revolutions per hour until they have been given 10,000 revolutions.

The contents of each cylinder is removed and that which will pass through a 16 mesh sieve is weighed. The loss of weight of the stone, as measured by the dust passing through a 1-16 in. mesh sieve, is the measure of the wear of the stone. The co-efficient of wear, as adopted by the National School of Roads and Bridges of France, is expressed by the formula, Co-efficient of wear $= 20 \times \frac{20}{W} = \frac{400}{W}$, where "W" is the weight of the dust which passes through a 1-16 inch mesh sieve in grams per kilogram of stone used.

It is thought that this test is valuable not only for determining the wearing qualities of crushed stone for macadam, but also for determining the suitability of stone for steps, sidewalks and flooring.

Specific Gravity.—The specific gravity determinations of building

*Sixth Annual report of the Massachusetts Highway Commission, page 60.

stones, which have thus far been made, are based upon two different conceptions. In the first case the specific gravity has been based entirely upon the mineralogical composition, being independent of the porosity of the stone. According to the second conception, the pores have been considered a part of the stone and the specific gravity computed for the exterior volume. The result according to the first conception has been designated by Regis Chauvenet as the "specific gravity proper;" that according to the second conception as the "apparent specific gravity." In case the porosity of the stone is less than one per cent., the specific gravity determined by either method is nearly the same, but where the porosity is more than 10 per cent. the results are very different.

The principal laid down by Prof. J. C. Smock,* that the specific gravity of the *particles, or mineral species,* composing the rock mass determines that of the stone, has been followed by most writers. The engineer, however, objects to this method because the weight of the stone per cubic foot in this case cannot be obtained directly by multiplying the specific gravity by 62.5 which is the weight of an equal volume of water. Unfortunately several contemporary writers on building stones have made the mistake of computing the weight per cubic foot by multiplying the "specific gravity proper" directly by 62.5. The following table shows the results of experiments on three different stones as published by one author:**

Number.	Specific gravity.	Weight in lbs. per cubic foot.	Per cent. of water absorbed.
C 2314.....	2.6236	163.50	18.17
C 2183.....	2.6166	163.07	3.62
C 2316..	2.5380	158.17	8.71

This table gives the weight per cubic foot of a stone which absorbed 18.17 per cent. of water as greater than that of the stone which absorbed only 3.62 per cent., although the difference in specific gravity is only .007.

Another writer says: "If we find that a stone has a specific gravity of 2.65 . . . we get its weight by simply multiplying 62.5 by 2.65 which gives us 165.62 . . ."† In this statement the specific gravity refers to "specific gravity proper" and not to the "apparent specific gravity." The weight per cubic foot obtained in this manner is obviously incorrect. Similar inaccuracies in the determination of the specific gravity

*Bulletin of the N. Y. Museum, Vol. II, No. 10, page 374, Prof J. C. Smock.

**Bulletin of N. Y. State Museum, Vol. II, No. 10, table page 358 by Francis A. Wilber.

†The building and decorative stone of Maryland, Maryland Geol. Sur. Vol. II, page 119, Geo. P. Merrill

is removed from the water and the surface quickly dried with bibulous paper, after which the specimen is again weighed. The difference in weight gives the increase due to the absorption. This difference divided by the weight of the dry stone is the ratio of absorption or porosity.

There are several errors in this method of determining porosity. The interstitial water is not easily expelled at a temperature of 100° C. If one wishes to expel the moisture from a stone within a moderate length of time, the stone must be dried at 110° C. Besides this, the sample cannot be completely saturated "by immersing in distilled water until bubbles cease to be given off." Finally the method of computation gives the ratio of absorption and not the actual percentage of pore space or porosity.

The porosity of a stone is best obtained in the following manner, using the determinations made in performing the tests for specific gravity. Subtract the average weight of the dry sample from the weight of the saturated sample. Multiply this by the specific gravity of the stone. This gives the weight of a quantity of stone equal in volume to the pore space and of the same specific gravity as the stone tested. The porosity or percentage of pore space will be this weight divided by the weight of the dry stone.

The ratio of absorption is easily obtained by dividing the weight of the absorbed water by the weight of the dry stone. In another part of this paper, it has been pointed out that the durability of a building stone is not indicated by its porosity or ratio of absorption. It was shown that the size of the pores is by far the more important consideration. When the size and shape of the grains and the percentage of pore space are known, one can estimate roughly the size of the pores. However, if only the ratio of absorption is available, the calculation of the size of the pores is liable to be less accurate. The porosity and not the ratio of absorption is the test which is desired. The porosity is usually higher than that of the ratio of absorption and may therefore meet with disfavor among quarrymen. When it is known, however, that the value of a stone cannot be estimated from its porosity, except when the size of the pore spaces is known, objections will cease to be made. The porosity should always be determined in preference to the ratio of absorption.

Weight Per Cubic Foot of Stone.—When first quarried, the weight of any stone depends upon its specific gravity, the amount of pore space and the water content. Of these, the only varying element is the water content, which in the more porous rocks, will vary at different seasons of the year, depending upon the thoroughness with which the stone has been seasoned. To determine the weight per cubic foot of stone which con-

tains an indefinite quantity of interstitial water is both unscientific and unsatisfactory. Such determinations depend upon a number of conditions, changes in any one of which will give a different result. The only constant weight is that of the dry stone.

The weight of a stone for commercial purposes may be obtained in two ways, first, by weighing directly a known volume of the stone which has been thoroughly dried at a temperature of 110° C.; and second, by computation from the data obtained in determining the porosity. The weight by the second method is determined by multiplying the weight of a cubic foot of water by the "specific gravity proper" of the stone and subtracting therefrom the weight of a mass of stone of the same specific gravity and equal in volume to the pore space of the given rock.

A simpler method would be to compute the "apparent specific gravity," as directed above, and multiply this by 62.5, which should give the same result.

Effect of Temperature Changes.—The durability of stone depends very largely upon its capacity to withstand changes of temperature. Such changes result in expansion and contraction of the mineral constituents and of the rock as a whole and may also result in the freezing and thawing of interstitial water, on account of which the stone may be weakened.

Thus far, comparatively few tests have been made to determine the effect on building stone of the alternate freezing and thawing of interstitial water. The importance of such experiments has never been questioned, but the difficulties in manipulation and the many conditions which need consideration before conclusions can be drawn from the quantitative results have had the effect of almost excluding these tests from the tests on building stone.

The effect of alternate freezing and thawing upon a stone saturated with water may manifest itself in three ways. First, cracks may form; second, small particles or grains may be removed from the surface, causing a loss in weight; third, the strength of the stone may be lessened. The first result is only occasionally observed in testing the samples in the laboratory owing to the careful selection of the pieces used in testing. However, where the bedding planes are prominent, these may open up, splitting the stone into thin layers. The second and third results usually occur and can be measured quantitatively in the laboratory.

The effect of alternate freezing and thawing of the interstitial water has been determined by two different methods, known as the natural and artificial. By the natural method, the samples are soaked in water and alternately frozen and thawed, a few or many times, at the convenience of the experimenter. By the artificial method, the stone is saturated in a

boiling solution of a soluble salt, such as sodium sulphate, and then allowed to dry. As the water evaporates, the salt crystallizes and expands producing stresses similar to those which result when water is frozen. The last method should be employed only when there is no opportunity to freeze the samples under conditions which more nearly accord with those present in nature.

Two-inch cubes should be used in making the freezing and thawing tests the same as in the previously described experiments. In case the experiments are made during the winter months, when the temperature is below the freezing point, the samples can be saturated with water which has been cooled nearly to the freezing point, and then placed out of doors. If freezing temperatures do not prevail in the climate where the experiments are being performed, access may be had to a cold storage building where the necessary temperature may be obtained. Freezing mixtures may also be used to obtain the desired temperature.

The samples which are to be tested should first be thoroughly cleaned and dried in a hot air bath at a temperature of 110° C. They should then be carefully weighed and saturated with distilled water, after the manner outlined in the discussion of the specific gravity test. The water used should be cooled almost to the freezing point before the cubes are removed to the place of freezing. They should be allowed to remain in the freezing temperature until thoroughly frozen and then thawed out. While freezing, the cubes should be placed in contact with a moderately porous stone which will serve as a natural drainage for the sample saturated with water. This operation should be repeated thirty or forty times after which the cubes should be dried in a hot air bath at a temperature of 110° C. They should then be weighed. The difference between this and the first weight will be the loss resulting from the test. The samples should be examined to discover any cracks that may have formed as a result of the freezing.

The frozen cubes should finally be crushed in a testing machine to determine their compressive strength. The results thus obtained should be compared with the tests made on unfrozen cubes of the same stone to ascertain the loss in strength.

The loss in weight during a period of thirty-five days is due mainly to the removal from the surface of small particles which are loosened in the process of cutting the sample. In the case of stone which has prominent bedding planes the loss may result from the removal of flakes or thin laminae. Where the stone is a dense fine grained limestone containing small cavities the corners may be broken off. The surface of the sandstone samples which have been sawed or hammer dressed contain many partly loosened grains which fall away from the mass of the stone

very readily. The freezing of the water which fills the minute cracks and pores at the surface exerts sufficient pressure to accomplish this.

The sedimentary rocks, such as sandstone, have more loose grains at the surface than finely crystalline limestone or granite. Except in case a stone is strongly bedded or contains cavities alternate freezing and thawing thirty or forty times will scarcely result in anything more than the removal of the loose particles from the surface. Sandstone in which bedding planes are absent will lose less in weight during a second period of freezing and thawing than during the first.

Determinations of the result of freezing and thawing on the strength of stone did not receive consideration until the publication of the Wisconsin report on "Building and Ornamental Stones." As stated in that report, it is thought that the determination of the loss in weight is of comparatively little value in estimating the effect of freezing and thawing on the durability of most stone. The opening up of cracks and the effect on the crushing strength are obviously more important. If a stone is saturated with water and repeatedly frozen while a portion of the pores are filled with water the adhesion of the particles must be weakened, although there may be no loss in weight. It is not reasonable to suppose that the strains produced can be measured by the direct loss in weight through the removal of particles from the surface. The deterioration from this cause can be better measured by determining the loss in strength. Experiments which were performed in the preparation of the report on "The Building and Ornamental Stones of Wisconsin," lead to the belief that this test is more important than the determination of the loss in weight. It is thought that this test, although not supplanting the other, will eventually take precedence over it in the testing of building stones.

Extreme Heat.—It is known from observation that rapid and extreme changes in temperature not only weaken a rock, but cause actual disintegration. The capacity to withstand extreme heat is one of the essential qualities of a good building stone. Brick, stone and wooden structures have suffered destruction alike in the great conflagrations in our cities. Brick and granite walls have crumbled into shapeless masses, while iron beams and girders have been melted and twisted out of shape.

Some materials are destroyed at comparatively low temperatures, while others are barely affected at a temperature above the melting point of copper. Very few building materials are unaffected by extreme heat.

Rocks are poor conductors of heat and for this reason the surface of a block may be highly heated, while the interior remains comparatively cold. The sudden cooling of a heated block of stone causes the contrac-

tion of the outer shell, resulting in differential stresses which may rupture the rock. The water which is thrown onto a burning building during a conflagration largely increases the danger of injury to the stone by causing rapid changes in its temperature. During winter the results are intensified by the freezing of the water which collects in the cracks formed by the alternating temperatures.

Thus far very few experiments have been performed to determine the effect of heat or cold when applied directly to stone. Such experiments as have been performed show that a stone will withstand a much higher temperature when heated and cooled slowly than when heated and cooled rapidly.

In making temperature tests two-inch cubes are placed in a muffled furnace and gradually heated to a high temperature. By using a standard pyrometer or substances of known fusibility, such as seger cones, the visible effects of the increase in temperature can be noted. Not only should one ascertain the effects of gradually heating and cooling the blocks, but he should also ascertain the effect of sudden cooling by plunging the samples when highly heated into cold water.

In the case of limestone or dolomite the effect of gradual heating will be manifest by calcination, while sudden cooling will result in flaking off the corners. Sandstone and granite may show very little outward appearance of injury, although their strength may be so affected, especially in the case of sandstone, as to permit of their being crumbled in the hand. When suddenly cooled, ordinary sandstone shows very little exterior evidence of injury, while granite usually flakes off at the corners. Very fine grained granite may show cracks without flaking. Stone which has been heated to a high temperature emits a characteristic ring when struck with metal. When scratched it emits a sound similar to that of a soft burned brick. This may be due to the loss of the water of composition by the minerals composing the rock.

Experiments which have thus far been performed seem to indicate that few, if any, stones will withstand, uninjured, a temperature of 1500° Fahrenheit. The stone which is least injured is apparently the one which has the simplest mineralogical composition and the most uniform texture.

A careful series of experiments, showing the loss of strength by each increase in temperature of 100° to 200° for the different kinds of building stones, would be both interesting and useful. To my knowledge such experiments have not thus far been performed.

Effect of Sulphurous Acid Gas and Dilute Sulphuric Acid.—The only kinds of stone which are to any degree affected by sulphurous acid gas or dilute sulphuric acids are those which contain calcium carbonate or calcium magnesium carbonate. The effect of sulphurous acid gas is de-

termined by placing two-inch cubes which have been carefully dried at a temperature of 110° C. in a wide mouthed bottle in which the air is kept moist by a beaker of water. The bottle should be sealed and sufficient sulphur dioxide transferred into it each day to saturate the atmosphere. The samples should remain in the bottle for thirty or forty days, and the atmosphere should be kept saturated with sulphur dioxide. After this, the samples should be removed, washed thoroughly and dried at a temperature of 110° C. The loss in weight should then be determined and the percentage which this is of the original weight of the cube is a measure of the effect of the gas.

The loss in weight is due mainly to the removal of calcium and magnesium salts which collect at the surface and are taken into solution when the samples are washed in water. In the case of dolomite the samples sometimes swell and crumble. If such samples are weighed before washing they will be found to have increased in weight, as a result of the change of the magnesium carbonate to magnesium sulphate.

Effect of Carbonic Acid Gas.—Carbonic acid gas only affects in a measurable degree those stones which contain calcium carbonate or calcium magnesium carbonate. Two-inch cubes are used for this test. They are washed and dried at a temperature of 110° C., after which they are placed in a wide mouthed bottle which is filled with carbonic acid gas. The atmosphere in the bottle is kept moist with a beaker of water. After being treated for a period of thirty or forty days, the samples are removed, washed, dried and weighed. The percentage of loss in weight is taken as the result.

It is probable that sulphur dioxide and carbon dioxide do not at any time exist alone in the atmosphere. The effect of these gases acting together, or in conjunction with the many less abundant gases, may produce results which are very different from those obtained for the gases separately in the laboratory experiments.

CHAPTER IV.

A BRIEF GEOLOGICAL HISTORY OF MISSOURI.

The conception of scientific men as to the origin of the earth and as to the position and shape of the original land surface, varies so widely as to make one hesitate somewhat in making statements relative to the early history of any portion of this continent. It has been believed by men of high authority that the North American continent existed at the earliest time with essentially the same outline that it has today. The forces of destruction and construction must have been operating at that time as they are today with greater or lesser activity. Orographic movements undoubtedly resulted in the formation of mountain ranges as stupendous as those which we know at the present time. There must have been orifices at the surface of the earth through which molten rock was extruded in the manner in which volcanoes are at the present time pouring out lava in other parts of the world. The volcanic activity on the continent as a whole was probably greater than it is today. At least there is evidence that the interior portions of the continent were, during this earliest period, the scene of volcanic activity such as is not known on the North American continent today. That Missouri had a part in this activity is shown by the rocks which are exposed in the southeastern part of the State.

The oldest rocks of which we have any knowledge are banded schists and gneisses which are classed with the metamorphic rocks. These rocks usually show evidence of intense folding and fracturing and seldom constitute desirable stone either for building or ornamental purposes. Frequently they have been so altered through metamorphic processes as to render their original texture and composition unrecognizable. These rocks belong to what is known as the Archean system. Many of the igneous and metamorphic rocks of this continent are younger in age than the Archean, although up to within a few years ago, it has been the practice to classify all the rocks which are of pre-Cambrian age as Archean.

In Missouri it has not been possible thus far to separate the Algonkin from the Archean. The igneous rocks are known to be of pre-Cambrian age and they have so very few of the characteristics of the typical Archean

as lead one to believe that they are chiefly Algonkin. In the southeastern part of the state, chiefly in St. Francois, Madison, Iron, Washington, Reynolds, Wayne and Shannon counties, there are areas of igneous rocks, chiefly granite and rhyolite, which have been intruded by diabase dikes. None of these rocks, with the exception of a small area at Pilot Knob, are of known sedimentary origin. If Missouri was submerged beneath the ocean at any time during the Algonkin period, there is little evidence of it at the present time. This part of the continent was apparently above the sea and may have consisted of lofty mountain ranges beneath which formed the massive granite bosses, which, after millions of years of exposure to the agents of weathering, are now exposed at the surface. The igneous rocks, which, for want of more positive knowledge, will be spoken of as pre-Cambrian in age, consist chiefly of granite and porphyry. The granite has either a gray or light to dark red color. In some places it is very fine grained and in others it is coarse, frequently porphyritic. The rhyolite has a black to red color and consists of a fine grained groundmass through which are scattered porphyritic crystals of feldspar. In some places the granite apparently grades into the rhyolite, there being no sharp contact between the two. It is understood, however, that the granite has been formed by the solidification of a molten magma deeply buried beneath other rocks. The cooling of the magma must have gone on slowly enough to permit the complete crystallization of all the mineral matter which it contained. These rocks are spoken of as being holocrystalline and as having a granitic texture. The individuals of quartz, feldspar and biotite or hornblende are intricately interlocked, giving the rock a strength seldom attained by those that have formed through sedimentation.

The rhyolite, commonly known as porphyry, formed under conditions which permitted only a partial crystallization of the magma. It is thought to have formed near or at the surface of the earth, which resulted in much more rapid cooling than in the case of the granite. Originally, the rhyolite had a glassy or vitreous groundmass, studded with crystals of feldspar. This groundmass is now finely crystalline as a result of changes which have been going on within the rock since it was formed.

Owing to its finer texture, the rhyolite has suffered more from earth movements than the granite. It is much more brittle, breaking more readily under stress. This has resulted in the production of many joints in the rhyolite while there are relatively few in the granite.

Together, the granite and rhyolite constitute an almost inexhaustible supply of excellent stone for building, monumental, paving and other purposes for which granite is used.

The first rocks which are of known sedimentary origin belong to the Cambrian period. This system of rocks is so closely associated with the overlying Ordovician beds, in most parts of the State, as to render impracticable a separation of the two at the present time. The beds which belong to the undifferentiated Cambrian and Ordovician periods are known together as the Cambro-Ordovician. These undifferentiated formations consist of sandstone and dolomite, aggregating from 800 to 1,000 feet in thickness.

The oldest formation of this series is exposed in the central part of the State and is known as the Proctor (Fourth Magnesian) limestone. This does not rest directly upon the granite. Drill records show that beneath this limestone there is a sandstone and perhaps another limestone formation. The Proctor formation consists of heavily bedded dolomite. It has a very uniform texture, but contains occasional irregular hackly cavities lined with dolomite, calcite and quartz, which might injure the stone more or less when cut and dressed for building purposes. The beds also contain occasional, promiscuously disseminated nodules of chert. The stone is crystalline and medium to coarse grained and has a bluish gray tint. This formation is only exposed in those places where the stream channels have cut deep into the Ozark plateau or local folds have brought the beds near the surface.

This formation contains a great quantity of stone which is admirably adapted to the rougher forms of masonry construction.

Above the Proctor formation is a thickness of from six to thirty feet of sandstone known as the Gunter (Third Sandstone). It appears that after the deposition of the Proctor limestone, this portion of the continent was elevated above the ocean. For an apparently short interval erosion and other forces of weathering were engaged in cutting down and trenching the land. This period was of short duration and the ocean soon covered this portion of the continent again, depositing the sandstone which now constitutes the Gunter formation.

This sandstone is fine to coarse grained, has a white to yellowish color and is rather soft. It is usually well bedded, frequently cross bedded. The areal distribution is comparatively limited, the exposures being confined to a few localities on the northern flanks of the Ozarks, where folding combined with erosion has brought the beds to the surface, and to limited areas about the flanks of the St. Francois mountains in the southeastern part of the State.

This formation in the central Ozark region may be the same as the LaMotte sandstone described in the earlier reports of this Bureau, as occurring unconformably above the pre-Cambrian in the southeastern

part of the State. However, there is considerable evidence that it is the equivalent of the shale and conglomerate horizon between the Potosi and Bonne Terre formations. The field work of this season will probably settle this point.

Very little of this stone is quarried owing to the abundance of better and more easily accessible stone with which it is usually associated.

Following the deposition of the Gunter sandstone somewhat deeper water prevailed and there was deposited a series of dolomite beds, known as the Gasconade formation (Third Magnesian limestone), in the central Ozark region. Providing the Gunter and LaMotte sandstones are the same, the Bonne Terre limestone or a part of it must be the continuation to the southeast of the Gasconade limestone of the central Ozark region. There is considerable difference between the Gasconade and Bonne Terre limestones. The Gasconade limestone has a thickness of from 240 to 250 feet in Miller county where it is typically exposed, while the Bonne Terre limestone in the southeastern part of the State is often between 500 and 600 feet thick. The Gasconade limestone contains an abundance of chert, either in layers or as disseminated nodules, while the Bonne Terre limestone contains no chert. On the other hand, the Bonne Terre limestone contains numerous thin layers of shale, usually in what are known as the shaly horizons, while the Gasconade limestone contains practically no shale. In case the Gunter sandstone proves to be the equivalent of the shale and conglomerate horizon between the Potosi and Bonne Terre, then the Gasconade and Potosi formations must be the same. These formations correspond more nearly in composition and thickness than do the Gasconade and Bonne Terre.

There are many beds in this formation from which stone suitable for bridge abutments, foundations and other forms of rough masonry may be quarried. Blocks of large dimensions may be obtained. This formation has a wide distribution over the Ozark plateau region.

Above this formation and conformable with it there is a series of alternating sandstone, chert and dolomite beds known in the central Ozark region as the St. Elizabeth formation. This may be the equivalent of the cherty horizon of the Potosi formation of the southeastern part of the State. Both the St. Elizabeth and the Potosi are highly siliceous, dolomite formations containing massive beds and nodules of chert and beds of sandstone. In the Potosi formation there is very little sandstone. It has been observed chiefly at the top of the formation as exposed in Washington county. If the St. Elizabeth and Potosi formations are not the same, then the former is above the latter and is represented in the southeastern part of the state by the sandstone, chert and dolomite beds which occur

at the top of the Potosi. In many places the dolomite is very subordinate. In the central Ozark region the St. Elizabeth contains locally thick beds of coarse to fine grained sandstone which occur in lenses at different horiozns in the formation. This formation has a very wide distribution throughout the Ozark plateau region.

Throughout the Ozark region the sandstone of this formation is quarried for buildings and sidewalks. It is medium to coarse grained, thickly bedded and has a reddish brown to yellow color. It is moderately hard and is considered one of the best and most durable sandstones in the State.

Above the St. Elizabeth formation and conformable with it is a series of dolomite beds known as the Jefferson City formation (Second Magnesian limestone). This formation consists of thick beds of siliceous, pitted dolomite alternating with thin beds of arenaceous, argillaceous dolomite. The thick siliceous beds are known as "pitted dolomite," while the argillaceous beds are known locally as "cotton rock." This formation occupies the more elevated parts of the Ozark plateau and is therefore more readily accessible to the quarryman than those underneath. This formation is beautifully exposed along the Missouri Pacific railroad between Washington and Jefferson City.

A great part of the stone used in the Ozark region is quarried from this formation. There are very few large quarries, but hundreds of small ones from which stone is obtained for local consumption.

After the deposition of the Jefferson City limestone this portion of the country was elevated above the sea, and eroded. It is uncertain whether this interval was short or long. It is known, however, that the land was eventually submerged, and that above the Jefferson City limestone there was deposited a considerable thickness of sandstone constituting what is now known as the Pacific or First sandstone. It is thought that this is a continuation of the St. Peters sandstone of Minnesota, Illinois and Iowa.

As a rule, this sandstone is soft and medium to coarse grained. In some places it is remarkably pure, being 99 per cent. silica. It occurs chiefly in the eastern part of the State, being found only in small isolated areas over the Ozark plateau. It has a variable thickness, there being in places one hundred or more feet exposed.

Above the Pacific sandstone a series of limestone beds were laid down, known as the Joachim formation or First Magnesian limestone. These beds have a very limited areal distribution, being best exposed in that section of the State lying between Crystal City, Pacific and Klondike. This formation contributes very little if any to the quarrying industry.

Throughout these formations there is a comparatively meager fauna. In the Gasconade and St. Elizabeth formations there are remains of brachiopods, trilobites and corals, while in some parts of the LaMotte sandstone one finds small lingula shells. Fossil remains of brachiopods and gasterapods have also been observed in some of the other Cambro-Ordovician formations, but they are not abundant.

In the eastern part of the State, along the Mississippi river, there are limestone and sandstone beds which are of known Ordovician and Silurian age. Of the Ordovician there have been recognized beds of Trenton limestone and Hudson River shale; of the Silurian, the Niagara and Lower Helderberg are the most prominent members.

These strata have not been positively recognized in the western part of the State. The greater part of the Ozark region, at that time, may have belonged to the land area.

The Trenton and Niagara limestones are quarried at a number of places, the stone being used for building purposes. The Trenton limestone is in places very pure, being 99 per cent. calcium carbonate. The Niagara is impure, being somewhat arenaceous.

At the close of the Cambro-Ordovician period it is thought that at least the southern and western portions of Missouri were elevated above the ocean, becoming a part of the continent. The distribution of Silurian and Devonian strata in the western and southern parts of Missouri has never been determined. Devonian and Silurian limestones occur in the northern and eastern portions of the State, and in most places are conformable with the underlying Cambro-Ordovician.

Wherever the Devonian has been observed, it is apparently conformable with the overlying Mississippian (Lower Carboniferous) system. The thickness of the Devonian has never been definitely determined, but probably does not exceed, at the place of its greatest development, 300 feet. It attains its greatest thickness along the Mississippi river between St. Louis and Hannibal. It thins rapidly to the west, being doubtfully present in the southwestern part of the State. The limestone of which this formation is composed is argillaceous. Whether or not this formation ever covered the region known as the Ozark plateau is unsettled.

The Mississippian or Lower Carboniferous series has a maximum thickness of from 1,500 to 1,600 feet.* It consists of several different series of rocks, among which Swallow and Broadhead distinguished the Chemung, Burlington (including the Keokuk), St. Louis and Chester. The rocks comprising the Chemung series are chiefly limestone, sand-

*The estimates of thickness of strata, as given in this chapter, are taken from the work of the earlier geologists and are not the results of our own observations.

stone and shale. Occupying a subordinate position in this series is the formation known as Lithographic limestone. The Chouteau limestone, also a member of this series, is quarried in some sections of the State, as is also the Vermicular sandstone. However, none of the stone from this series occupies an important place in the quarrying industry.

The Burlington limestone is a very important building stone. It also constitutes one of the chief sources of limestone used in the manufacture of quick lime. The quarries at Carthage, Phenix, Hannibal, Louisiana and other places are located in this formation. This limestone is in some localities remarkably white. It is exceptionally high in calcium carbonate, frequently containing over 99 per cent. The St. Louis limestone, which overlies the Burlington, is the chief source of rubble and crushed stone for St. Louis and vicinity. It has a thickness of about 250 feet, but a comparatively limited surficial distribution.

The rocks of the Mississippian system outcrop over an extensive area in northeastern and southwestern Missouri, surrounding the Cambro-Ordovician, Silurian and Devonian rocks of the Ozark plateau. An idea of the area covered by the rocks of this system can best be obtained by reference to the geological map accompanying this report. The sea in which these rocks were laid down supported myriads of Marine animals, the shells of which make up a greater part of some of the beds of this formation. The Burlington limestone is in some places a mass of crinoid remains. So thickly is this limestone studded with these fossils that it was called by the early geologists the "encrinital."

It is believed that, following the deposition of the rocks of the Mississippian system, some portions of Missouri were elevated above the sea. At least in some places there is an unconformity between the beds of the Mississippian (Lower Carboniferous) system and the overlying Pennsylvanian (Upper Carboniferous). The Pennsylvanian system, according to Winslow, consists of from 1,800 to 2,000 feet of limestones, sandstones and shales, associated with which occur seams of coal. This system is usually separated into the Missouri or Upper Coal Measures and the Des Moines or Lower Coal Measures, constituting a conformable series of strata. The surficial extent of the Pennsylvanian system in Missouri can best be seen by reference to the geological map. It occupies chiefly the northern and western sections of the State, although there are small isolated areas throughout the Ozark region which are too small to be shown on the map. The small pockets of coal and shale occurring in some of the more elevated portions of the Ozark plateau are very good evidence that the system probably covered the entire State, with the exception, perhaps, of some of the more elevated peaks or knobs of the St. Francois mountains.

After the deposition of the Pennsylvanian strata, a greater part of Missouri became permanently a part of the North American continent. Only in the southeastern section do we find the sea again encroaching on Missouri territory. Here, according to Winslow, there are small thicknesses of Cretaceous and Tertiary rocks representing an accumulation of not over 400 feet of sediments, which, as a rule, are unconsolidated and therefore unfit for quarrying.

During Pleistocene times, the glacial ice sheet covered that portion of the State north of the Missouri river. In two or three places the ice may have passed beyond the Missouri river, as is shown by the drift in Saline and adjacent counties. North of the river the land is covered with boulder clay, sand and gravel deposited by the ice. This mantle of drift is frequently 250 feet in thickness. The movement of the ice sheet over the surface and the accumulation of drift naturally modified greatly the surface of the land, by removing elevated portions and filling depressions. In many instances outcrops of rock which might otherwise be exposed for quarrying have been deeply buried. The glaciers brought from the north numerous boulders of granite and other igneous rocks, which constitute a source of supply for building stone in some parts of the State. These boulders, however, are not as abundant as in the northern states.

Since the Carboniferous period the greater part of the State south of the Missouri river has been subjected to erosion. Since Pleistocene time the entire State has been under the influence of the weathering agents. The streams in the southern part of the State have cut deep valleys and trenches through the rocks, exposing them in such a manner as to make inviting localities for quarrying. In the northern part of the State the exposures are less numerous, the valleys are much gentler, and the opportunities for quarrying are correspondingly few. However, we have in the State most of the important kinds of stone now quarried for economic purposes. There is a sufficient range in kinds of building stone to satisfy the taste of almost anyone.

The geological history of the State has been one of constant change and these changes have brought about the deposition of sediments of various kinds, providing almost as great a variety of rocks, as can be found in any other state in the Union. Quarrying is made easy in many places through the rectangular system of jointing and the bedding planes, by which the stone is broken into blocks which can be easily handled. In some quarries the joints are close together and in others they are far apart. Altogether they probably lessen very much the cost of quarrying.

CHAPTER V.

PRE-CAMBRIAN.

GRANITE AND RHYOLITE (PORPHYRY).

The igneous rocks of Missouri are all of pre-Cambrian age and with one exception are confined to nine counties in the southeastern part of the State. These counties are Madison, Iron, St. Francois, Ste. Genevieve, Wayne, Carter, Shannon, Reynolds and Washington. The distribution of the pre-Cambrian rocks is shown on the accompanying geological map of the district. The map shows one large irregular area in Madison, St. Francois, Iron and Washington counties, and numerous small irregular areas east, south and west of this main area. In Wayne and Iron counties, the igneous rocks occur in numerous small, isolated, roundish knobs. In the east central part of Shannon county they also occur in isolated, roundish hills, the largest of which are from one to three miles across. In Carter county the outcrops consist of three or four small knobs covering very limited areas. In the west central part of Ste. Genevieve county there are three isolated areas. To the region embracing a greater portion of the igneous rocks of this district, Winslow has given the name St. Francois Mountains.

These granitic rocks constitute, chiefly, the more elevated portions of the land. Some of the hills are 1,800 feet above sea level and from 500 to 800 feet above the adjacent valleys. There are no continuous ridges or mountain ranges, the hills and knobs being scattered promiscuously over the district. There are very few escarpments or rugged cliffs. The hills generally rise rather rapidly, but with well rounded outlines. Many of the knobs are separated by rather narrow valleys. The hills which are composed chiefly of rhyolite, usually stand out in much bolder relief than the granite knobs. The differential weathering of the igneous and sedimentary rocks is beautifully shown in this district.

As determined by Haworth, these rocks are undoubtedly of igneous origin and of pre-Cambrian age. They were formed through the solidification of molten material long before the limestones and sandstones were laid down. Before the sedimentary rocks were formed, they con-

stituted an important part of an extensive mountain range, and are probably the stumps of what were formerly lofty peaks. During Cambrian time they were probably in part submerged, as shown by the sandstone and limestone which flank many of the knobs. During most of the period which has elapsed since Cambrian time, they have been a part of the continent, and as such have been exposed almost continuously to weathering. Erosion has removed a large part of the surrounding sedimentary rocks, uncovering more and more of the granite and rhyolite which are being broken down and removed, although much more slowly than the sedimentary rocks.

The igneous rocks of this district consist mainly of granite and rhyolite, which have been cut by numerous diabase dikes. The major portion of the granite, as shown on the map (see plate XII.), is in an area of about 110 to 120 square miles, west and southwest of Knob Lick. The remaining granite occurs in very much smaller areas, seldom exceeding two miles in cross section. These are scattered, promiscuously, through the district, but occur in greatest numbers within a radius of ten miles of Fredericktown, in Madison county.

A great part of the pre-Cambrian rocks of this district are rhyolite, which predominates, especially in the western half of the district. The rhyolite surrounds the main body of granite almost continuously on the northwest, west and south. The numerous small areas of igneous rocks in the western and southwestern parts of the district are chiefly rhyolite.

Both the granite and rhyolite are cut by numerous diabase dikes, especially in the eastern and southeastern parts of the district. These dikes vary from one inch up to more than six feet in width.

The texture and composition of the granite and rhyolite have been discussed in detail by Haworth in Vol. VIII, of the reports of this Bureau. Much of the granite has a porphyritic texture, although there is considerable variation in the textures of the granites from the different areas. The granite at a number of the quarries has a medium grained matrix in which are embedded large crystals of feldspar. The granite in the quarry at Cornwall is the coarsest grained of any that is being quarried. It is considerably coarser grained than that from either the Knob Lick or Graniteville areas. The Knob Lick granite is medium grained, but varies somewhat in different parts of the area. However, as a rule, it is finer grained than the granite from the other quarries. The Graniteville granite is somewhat coarser than that quarried in the Knob Lick area.

The gradation of rhyolite into granite and vice versa can often be traced horizontally and vertically. The rhyolite everywhere has a very

finely crystalline ground-mass, in which are embedded phenocrysts of quartz or feldspar, varying in size from those that are microscopic to those one-half an inch in diameter.

In color the granite varies from light gray through different shades of reddish pink to brownish red. The prevailing color is some shade of red. The color of the rhyolite varies from many shades of dark red and wine color to dark brown and black. Where the phenocrysts are large the color is somewhat mottled, giving the stone a general grayish brown tint

The dikes are fine grained, greenish black or black rocks, called diabase, which have been injected into the granite and porphyry. This rock often has a finely porphyritic texture, although much of it is apparently homogenous throughout. The dikes are from one inch to six feet in width and are generally broken into small blocks by many vertical and horizontal joints.

The granite is composed chiefly of orthoclase, quartz and biotite with minor quantities of hornblende. Among the accessory minerals are apatite, which is occasionally present as an original constituent; zircon, which occurs in very small grains; and magnetite and hematite, which occur in small quantities in all the granites. Chlorite occurs along the weathered surfaces and jointing planes. A number of other minerals have been found associated with the dike rocks at the "silver mines." Among these are sericite, zinnwaldite, topaz, fluorite and wolframite.

HISTORY.

The first extensive granite quarry in Missouri was opened in 1869, at Graniteville, by Phillip Schneider of the Schneider Granite Co. This quarry is now known as the west opening of the Syenite Granite Co. The land on which this quarry is located was first leased by Mr. Schneider from the Iron Mountain Ore Co. At the expiration of his lease, Mr. Schneider purchased the land upon which the present quarry of the Schneider Granite Co. is located. In 1874, Milne and Gordon opened the first quarry at Syenite, which quarry they have operated up to the present time. The Syenite Granite Co., one of the largest granite companies in Missouri, opened a quarry at Syenite, in 1880. They operated it about three years, after which they moved to Graniteville, leasing the land first developed by Mr. Schneider. In 1889, Sheahan Bros. opened a quarry at Graniteville. The Schneider Granite Co., the Syenite Granite Co., Milne and Gordon and Sheahan Bros. are now the principal producers of dimensional and monumental granite in this State.

The first quarries produced mainly dimensional and monumental stone, but after the introduction of granite blocks for paving in St. Louis,

the paving block industry attained considerable proportions At that time paving blocks sold for $80 to $90 per thousand, and a block maker, after paying a driller, could easily earn from $5.00 to $7.00 per day. As a result, many small quarries, locally known as "motions," were opened, especially in the vicinity of Syenite. At Graniteville, the paving block industry has been confined mostly to the large quarries, at which the material not suitable for monuments or buildings is manufactured into blocks. Most of the paving block manufacturers leased the land upon which they worked, paying a royalty, based upon the number of blocks made.

The motions mentioned above consist of small, irregular, shallow openings from which the granite can be quarried without machinery. Sometimes large boulders lying on the surface are broken into blocks. Most of the boulders and the outcrops from which the stone could be quarried easily at Syenite have been worked until now there are very few favorable and inexpensive places at which to open "motions." The price of blocks has declined about 50 per cent. and consequently nearly all of the motions have been abandoned. The manufacture of blocks is now confined chiefly to the large quarries in which the poor stone is used for this purpose. At present the only motions that are being worked are at Bee Knob, locally known as Klondike Hill, about four and one-half miles west of Knob Lick. There are a great many "motions" on this hill, most of which have been abandoned. When the granite quarrying industry was in its prime, a number of quarries were opened at Skrainke postoffice and Buck Mountain, about seven miles south of Knob Lick, but these have not been operated for a number of years.

The fall in the price of paving blocks may be attributed to a number of causes. First, fewer granite blocks are being used in St. Louis. Second, the introduction of Georgia granite, which, on account of its schistose structure, is less expensive to work into blocks.

During the past few years there has been a large increase in the use of crushed granite for paving and concrete and as a result this is the chief product of a number of quarries. Although a macadam pavement will not wear, without repair, as long as one built out of granite blocks, yet with a correct system of maintenance, it will last indefinitely. One of the chief advantages of a macadam pavement is its quietness, compared with granite blocks.

Spalls and broken surface boulders are shipped quite extensively from quarries not having crushing plants to crushing plants in St. Louis. For this purpose the fresh granite is preferable to that which is decomposed.

Missouri red granite has a rich, subdued, warm red color, on account of which it has been constantly in demand as an ornamental and monumental stone. At the present time the demand for monumental stock is particularly strong. The universal demand for Missouri red granite is shown by the orders for car load lots which are received from all sections of the country, including California, Canada, Illinois, Massachusetts and even Vermont.

The rhyolite is not a popular building or ornamental stone. In the quarries which have been opened it is so badly broken with joints that pieces sufficiently large for building or monumental stock can only be obtained with difficulty. The rhyolite has been used to some extent for paving blocks, but its fine texture causes the surface to wear smooth and slippery, on account of which it is no longer used. It takes a very good polish and many of the tints are especially beautiful. However, the small size of the blocks makes it impracticable to develop the stone for this purpose.

BEE KNOB.

This place, which is known locally as Klondike Hill, is a "knob" of granite, about four miles west of Knob Lick. Small quarries have been developed at many places on the hill, but no large ones. Quarrying was begun in 1890 and has been continued intermittently up to the present time.

Very few of the quarries are more than ten feet in depth, being usually confined to the uppermost bed. Whenever quarrying became difficult or expensive, the openings were abandoned for more favorable localities.

The color of the granite varies from a slightly reddish gray to a light red. It is medium to fine grained, and consists chiefly of feldspar and quartz, with a lesser amount of biotite.

These quarries, or motions as they are called, are worked on a royalty basis. The land is owned by Wm. Taylor and the Iron Mountain Ore Co., the former charging a royalty of 5c per hundred for six inch blocks and 10c per hundred for eight inch blocks, and the latter a royalty of ten cents per hundred for all sizes. Two dollars royalty is charged for every thousand linear feet of curbing.

The only active quarries are located on the southwest side of the hill and are being operated by Alexander Hansan, Wood Bros., and Andrew Raby. The following is a description of each of these quarries:

THE ALEXANDER HANSAN QUARRY.

This quarry has a face about 75 feet long which coincides with the major joints. These joints strike N. 43° E. and are from four to twelve feet apart, greatly facilitating the quarrying of the stone. Quarrying has extended down to the first bedding plane, eleven feet below the surface. The granite contains numerous dries which make it unfit for monumental stock. The stone works very well into paving blocks and curbing, which are the principal products of the quarry. The largest blocks are moved by hand derricks.

THE ANDREW RABY QUARRY.

This quarry has been opened for a considerable distance along the west crest of the hill. A three-foot ledge of granite is being worked, chiefly into paving blocks.

THE WOOD BROS. QUARRY.

This quarry is located west of the Hansan quarry. It has a vertical face of from ten to fifteen feet of what is apparently excellent stone for making paving blocks. It contains numerous dries which make the stone unfit for building or monumental stock.

RÉSUMÉ.

The product of these quarries is hauled by wagon, two miles, to the Turpin switch. The curbing and paving blocks are shipped to St. Louis. At this switch, the Heman Construction Co. operates a crusher which is owned by the Turpin Granite Co. Spalls are sold to this company for 50c per ton, delivered. A quarry was formerly operated near where the crusher now stands, but this was abandoned several years ago. It has a vertical face of about 55 feet without bedding planes. The granite has a light red color and is similar in texture to that at the Zeran Gregory quarry. The company finds it cheaper to purchase spalls from the quarries at Bee Knob than to quarry from this ledge.

The crushing plant is equipped with No. 2 and No. 4 Gates crushers, steam hoist, derricks and other accessories.

CORNWALL.

THE MILNE & GORDON QUARRY.

This quarry is located one-fourth of a mile northwest of Cornwall and west of the St. Louis, Iron Mountain and Southern railway. It is situated on the southeast side of a granite knob.

It consists of an irregular opening 250 feet by 200 feet, having a maximum vertical face of about eighty feet. There is practically no stripping. Near the middle of the quarry occurs a diabase dike two feet in thickness, striking N. 55° W.

The granite is coarser grained than in any of the other quarries inspected. It consists essentially of orthoclase and quartz with a lesser amount of biotite. Some of the feldspar individuals are very large, having a cross section of one inch. The quartz grains are occasionally three-eighths of an inch in diameter, while the biotite occurs chiefly in small flakes.

The granite has a deep red color, very similar to that at Graniteville. It is a little darker than the Graniteville stone and is much deeper colored than that at Syenite.

The major joints strike N. 40°-45° W. Minor sets strike N. 19° E., N. 25° W. and N. 70° W. These joints are so numerous that the stone can seldom be obtained in blocks large enough for buildings or monuments. Large pieces have been obtained, but, in general, the stone cannot be quarried profitably for these purposes. The stone also contains small dark veins which injure a part of it for monumental work.

The company has a crushing plant located one-fourth of a mile southeast of the quarry, to which the stone is carried by a gravity tram. A short siding connects the crushing plant with the St. Louis, Iron Mountain and Southern railway. At present the chief product of the quarry is crushed granite.

GRANITEVILLE.

The largest and most important granite quarries in the State are located at Graniteville five miles northwest of Ironton, the county seat of Iron county. As may be seen by consulting the map of the district, the granite areas in this vicinity are comparatively small, consisting of two outcrops, a half a mile apart. The color, texture and composition of the stone at the two places indicate that they belong to the same granitic mass.

The north outcrop consists of an elongated hill or ridge one and three-fourths miles long and one-fourth to three-eights of a mile wide. This granite is flanked on all sides, except the northeast, with limestone of Cambrian age. On the northeast side it grades into porphyry. The hill rises rather gradually from 100 to 130 feet above the surrounding country. The quarries on this hill produce the greater part of the monumental and dimensional granite quarried in the State.

The south outcrop is locally known as the "wild cat." It is about a

RED GRANITE.
Quarry of the Schneider Granite Company, Graniteville, Mo.

half a mile long by a fourth of a mile broad. The granite is very similar to that at Graniteville. A quarry was opened on this hill several years ago, but very little stone has been taken out.

The granite of this locality has a very uniform texture and color. The essential constituents are orthoclase, quartz and biotite. The individuals of feldspar and quartz are intricately interlocked and seldom have crystal faces. The grains are of medium size. Occasional larg feldspar crystals, sometimes two inches long, occur imbedded in the granitic ground-mass, giving the granite a porphyritic texture. Occasionally, the feldspar, quartz and biotite individuals are seggregated, separately, in large masses, rendering the stone unfit for structural work. The color of the granite, which is a deep red, is quite uniform throughout the different quarries. It is due to the pink feldspar and red iron oxide constituents. Most of the quartz is translucent. The biotite and hornblende have very little effect upon the color of the stone.

The preponderance of the two relatively hard minerals, feldspar and quartz, render the granite susceptible to a very high polish.

Probably one of the most striking illustrations of the way in which granite weathers occurs at Graniteville, where huge residual boulders are scattered over the surface. Just west of Graniteville these are especially picturesque and instructive, and on account of their peculiar shape are known as the "elephant rocks." (See frontispiece.) These enormous boulders, which are from ten to twenty-five feet in diameter, have a roughly spherical or oval shape, due to weathering along the edges and corners of the blocks produced by the jointing planes. At this place the boulders occur in quite well defined rows, conforming very nearly in direction to the major system of joints. The feldspar decomposes more readily than the quartz, leaving the grains of the latter protruding at the surface. The granite is frequently covered to a depth of from one to three feet with quartz grains which were loosened when the feldspar was decomposed. Upon the weathered surface and along joints and beds, kaolin, formed by the decomposition of the feldspar, frequently occurs, partially filling the space originally occupied by the feldspar.

Examples of all stages of weathering, from that in which the surface joints are just being opened through decomposition, to that in which the blocks between the joints are entirely rounded, may be seen in this area. The sap rarely extends beyond a few inches into the stone.

Quarries are being operated at this place by the Schneider Granite Company, the Syenite Granite Company and Sheahan Bros.

THE SCHNEIDER GRANITE COMPANY'S QUARRY.

This company was incorporated in 1890 for $150,000, and the present officers are P. W. Schneider, Sr., president; R. P. Schneider, vice-president, and B. Schneider, secretary. The company has offices at 330-331 Lincoln Trust building, St. Louis. They control about 40 acres of land, underlain with granite suitable for quarrying. This quarry is located about three-fourths of a mile north of Graniteville in the S. E. ¼ of N. E. ¼, sec. 10, T. 34 N, R. 3 E. It consists of two openings. One is some distance east of the plant, on the west side of the hill, and the other is southeast of the plant. The latter is being worked more extensively. It has an irregular rectangular outline, about 200 feet east and west by 150 feet north and south. A track connects it with the plant. Just north of this opening is a rectangular sunken opening, about 100 feet square and 45 feet deep. The top of this quarry is on a level with the base of the one just south of it.

The granite is medium to coarse grained and consists mainly of orthoclase and quartz, with occasional individuals of biotite. The texture differs very little throughout the quarry. In the lower portion of the first opening, the granite is somewhat finer grained than near the surface. The color, which is a strong red, is uniform, although it is slightly deeper in the lower portions of the quarry. In the east end of the quarry there is a slightly bluish streak a foot wide. North of where the granite is being worked in the upper opening it is not quarried on account of its color.

The quarry was opened near the northwest corner by exploding several tons of powder in two chambers at the bottom of a shaft sunk in the granite. This opened the joints over a wide area and broke a considerable quantity of the granite into very small pieces. The granite has been worked beyond this area and now presents a solid face.

The major joints strike N. 41-45° E. and are from four to thirty-five feet apart. These are known as the "rift seams" because the stone splits most readily parallel to them. The minor joints strike N. 45-50° W. and are especially numerous in the west end of the quarry, where they are from two to four feet apart. Occasional other joints strike diagonally across these. The principal bedding plane is twenty-three feet from the surface and lies approximately horizontal. Dries spoil many blocks that would otherwise be perfect. These seams are usually short and often do not appear until the block is being worked in the shed. Short, disconnected, dark streaks, parallel to the rift, occur in some parts of the quarry. These are frequently an eighth of an inch wide and contain small

RED GRANITE.
Mill blocks ready for shipment at the Schneider Granite Co.'s quarry, Graniteville, Mo.

crystals of iron pyrite which alters to yellowish brown iron oxide when exposed to the weather. Occasional, thin dark veins occur parallel to the lift. All the seams, of whatever character, cause some waste, since the monumental and building stock should be without blemishes.

The principal bedding plane is of great assistance in getting out the stone. Above this bed solid blocks of almost any size can be obtained. Granite has been quarried about 30 feet below this bed, but no other bedding plane has been encountered. The face of this portion of the quarry is very irregular.

From the opening just north of this an excellent granite is obtained in large blocks which are practically free from defect. The twelve polished columns in the Flood building in San Francisco, which are sixteen feet long by two feet six inches in diameter, were quarried from the lower portion of this opening. The imperfect blocks and spalls from this quarry are crushed.

The third opening, located east of the plant, was opened by exploding a large mine of powder near the N. W. corner. This opening has an irregular triangular shape, and a vertical face of about sixty feet. The granite is very similar to that in the west opening.

The quarry contains numerous joints which strike in many different directions. The most prominent strike N. 70° W. (dip 30-50° S. 20° W.); N. 45° E.; N. 80° W.; and N. 55° E. These joints, some of which were undoubtedly caused by the explosion of the mine, break the stone into such small blocks that very little dimensional stone is obtained. This granite is being used almost exclusively for paving blocks and crushing. The outcrops to the north indicate that excellent stone will be obtained when the opening is extended in that direction. Two-inch cubes of this granite gave a crushing strength of 19,452.5 pounds per square inch.

The quarry is connected with the St. Louis, Iron Mountain and Southern railroad, at Iron Mountain, by a spur three and seven-eighths miles in length. The company owns a locomotive, large steam derricks, two No. 4 Gates crushers, having a capacity of 200 tons per day; two 60-horse power engines, and two 75-horse power boilers which furnish the power for operating the entire plant. The cutting shed is equipped with five lathes, Jennie Lind polishers and all other machinery and tools needed for cutting granite. This company is producing building stone, monumental stock, paving blocks and three sizes of crushed granite, ⅜ inch, ¾ inch and 1½ inch. The last is sold F. O. B., Iron Mountain tracks, at prices ranging from $1.45 to $2.00 per ton. Very few paving blocks are made, although formerly 50,000 to 60,000 were produced per month. An average of 65 men and as high as 150 men are employed, exclusive

RED GRANITE.
Sheahan Bros. quarry, Graniteville, Mo.

RED GRANITE.
Methods of quarrying at Sheahan Bros. quarry, Graniteville, Mo.

This quarry is producing monumental stock, dimensional stone and paving blocks. Spalls, which are shipped to St. Louis, bring seventy-five cents per ton, delivered at the St. Louis, Iron Mountain and Southern railroad.

The equipment consists of three steam drills, two steam hoists, a large derrick, two pumps and a 100-horse power boiler. About twenty men are employed. The entire product is hauled by wagon to the railroad, a distance of two and one-fourth miles. It is expected soon to build a spur from the railroad and to erect a crushing plant.

THE SYENITE GRANITE COMPANY'S QUARRY.

The first quarry operated by this company at Syenite was opened in August, 1880, and abandoned about 1890. In March, 1882, the company leased all the granite land, in the vicinity of Graniteville, owned by the Iron Mountain Ore Company. The first quarrying by this company at Graniteville was in the opening formerly worked by Mr. Schneider just west of the company's store. Two years later an opening, which is still operated, was made north of Graniteville, in the S. W. ¼ of the S. W. ¼, sec. 11, T. 34, R. 3 E. The officers of the company are R. W. Allen, president, T. F. Wash, vice-president, and H. W. Allen, secretary. The company has offices at Graniteville and at 125 S. 4th street, St. Louis, Missouri.

The opening which is being worked extends into the hill about 340 feet and has a south face 500 feet long. The face is ten feet in height near the west end and gradually increases to approximately sixty feet near the east end.

This quarry was opened by exploding twenty thousand pounds of powder in each of two chambers eighty feet apart and eighty feet below the surface. Before exploding the powder, the shaft and drifts connecting the chambers were filled with spalls. The discharge of these mines opened the joints over a considerable area, and in close proximity to the chambers the stone was broken into very small pieces.

The essential constituents of the granite are orthoclase and quartz. The grains are of medium size, although there is an occasional feldspar crystal two inches in length. Biotite is a minor constituent which is occasionally segregated in masses of variable size. The color which is a warm, dark red, similar in most respects to the granite at the other quarries, is very uniform throughout the quarry.

The major joints strike N. 60° E., dip about 10° and are from two to twenty-five feet apart. A minor set which is poorly developed in this quarry strikes at right angles to the first set. Near the middle of the

The area covered by the large surface boulders has been wisely protected from the quarryman, and these most excellent illustrations of the sub-aereal decomposition of granite have not been molested.

The following list contains the names and locations of some of the important buildings, which have been, wholly or in part, built out of granite from this area. The dimensions of some of the large pieces of granite quarried are also given, affording one an idea of the size of the blocks that may be quarried.

Traction Building, Cincinnati, Ohio, Fifth and Walnut.
Lindell Building, St. Louis, Fourteenth and Washington.
Granite Building, St. Louis, Fourth and Market.
Equitable Building, St. Louis, Sixth and Locust.
Eads Bridge, St. Louis, Piers.
Merchants' Bridge, St. Louis, Piers.
Benton Monument, St. Louis.
Star King Monument, San Francisco.
Twelve Polished Columns 16 ft. long, 2 ft. 2 in. diam, Flood Building, San Francisco.
New Washington University Buildings, St. Louis.
St. Charles Hotel, New Orleans.
John F. Davis, residence, St. Louis, Westmoreland Place.
Custom House, Memphis, Tenn.
State House, Springfield, Ill.
Commercial Building, St. Louis, Mo.
Rosenheim Building, St. Louis, Mo.
Liggett & Meyer's Building, St. Louis, Mo.
Fagin Building, St. Louis, Mo.
Merchants' Bridge and Terminal Railway, St. Louis, Mo.
Security Building, St. Louis, Mo.
Inlet Tower, St. Louis Water Works, St. Louis, Mo.
Anheuser-Busch Brewery Buildings, St. Louis, Mo.
Odd Fellows Hall, St. Louis, Mo.
Mercantile Library Building, St. Louis, Mo.
Vandergriff Building, Pittsburg, Pa.
F. E. Knowles & Co., San Francisco, Cal.
Paxton Building, Omaha, Neb.
Indianapolis Union Depot, Indianapolis, Ind.
Society for Savings Building, Cleveland, Ohio.
Blatz & Krebs, Louisville, Ky.
Henry U. Krankel, Louisville, Ky.
Thos. Allen Monument 42 tons in one piece, Pittsfield, Mass
U. S. Custom House and Post Office, St. Louis, Mo.
New City Hall, St. Louis, Mo.
U. S. Custom House and Post Office, Cincinnati, Ohio.
Marshall-Field Building, Chicago, Ill.
The Rookery, Chicago, Ill.
The Rialto, Chicago, Ill.
Studebaker Building, Chicago, Ill.
Monadnock Building, Chicago, Ill.
Kearsarge Building, Chicago, Ill.
Whitney National Bank, New Orleans, La.
Art Museum, Cincinnati, Ohio.
First National Bank, Cincinnati, Ohio.
New City Hall Extension, Cincinnati, Ohio.
Oriental Hotel, Dallas, Texas.
Central Savings Bank, Baltimore, Md.
Keith & Perry Building, Kansas City, Mo.

RED GRANITE.
Thomas Allen Monument, Pittsfield, Mass.

Savery Hotel, Des Moines, Iowa.
Sloan Monument, Woodlawn Cemetery, St. Louis.
Polished Monument, 42' x 4'2". Weight, 42 tons.
Twenty-six Lintels in Marshall-Field Building, 8 tons each.
Two Polished Columns in Studebaker Building, 3'8" x 12'6". 14 tons each.
Two Carved Lintels in Mercantile Library, 24 tons each.
One Carved Lintel in Odd Fellows Building. 20 tons.
Two Base Stones in arch at Pittsfield, Mass., 17 tons each.
One Base Stone in Liggett and Meyer's Building, St. Louis, of 30 tons.

KNOB LICK.

The most extensive quarrying operations in the eastern part of the granite district are centered about Knob Lick. There is a greater area of granite here than at Graniteville, and also a greater number of quarries, although none are so large.

The first quarry in this district was opened at Syenite, in 1874, by Milne and Gordon, and has been operated continuously since that time. In 1881, the Syenite Granite Co. opened a quarry on the south bank of the St. Francois river north of Syenite, which was operated extensively until the company opened a quarry at Graniteville, when it was abandoned. After the Milne and Gordon quarry was opened, many smaller ones were opened on the neighboring hillsides. There are great numbers of these west and northwest of Knob Lick, but from none of them has any considerable amount of stone been quarried.

The greatest activity was twelve to eighteen years ago, when the manufacture of paving blocks was at its height. It was during this period that the small quarries, referred to above, were opened. Wherever there was a favorable opportunity, openings were made and paving blocks manufactured. Hundreds of block makers were at work and millions of blocks were produced. These small quarries, known as "motions," were often started by working a large boulder lying on the surface. They seldom extend deeper than the first ledge, which is from two to ten feet in thickness. As a rule, no attempt was made to open any of them on a large scale. When the stripping became excessive or the stone difficult to quarry, operations were transferred to another locality. Both granite and rhyolite were used for making paving blocks, the former more extensively. Practically all of these small quarries were worked on a royalty basis. A person opened a quarry wherever he chose, paying the owner of the land a royalty on every hundred blocks manufactured.

At Skrainka postoffice, five and a half miles south of Knob Lick, several quarries were opened in the rhyolite. Considerable quarrying has also been done west of Holladay and Buck Mountains, five miles southwest of Knob Lick. The output from these quarries was hauled by team to the railroad, a distance of from three to five miles.

The chief product of the quarries in this area has been paving blocks. The lessened demand for this product in St. Louis has resulted in the abandonment of hundreds of small paving block quarries or "motions." The only ones now being worked are at Bee Knob about four miles west of Knob Lick.

Considerable monumental and dimensional stock has been produced, chiefly by Milne and Gordon who are the only persons making a specialty of this product.

As a result of the increasing demand for crushed granite, a number of well equipped crushing plants have been built. At present the output of crushed granite exceeds that of any other product.

The spalls from the abandoned quarries and small partly decomposed boulders gathered from the surface are shipped to St. Louis to be crushed and used in macadam and concrete work.

The color and texture of the granite vary considerably, being less uniform than in the Graniteville area. This does not apply to individual quarries, from most of which stone of uniform color can be obtained. The essential constituents of the granite are feldspar, quartz, biotite and an occasional crystal of hornblende. In general, the granite is somewhat finer grained than that at Graniteville.

The granite varies in color from a gray, through a grayish red, to a red. Nowhere is the color of the fresh stone as deep a red as that at Graniteville. It contains more biotite than the Graniteville granite and small black spots are more abundant. In the gray varieties, the biotite gives the stone a bluish color when viewed from a short distance. For this reason, it has come to be known locally as "blue granite." In the red varieties, the feldspar is not as deeply colored as it is in the granite from Graniteville. This accounts for the more subdued color of the Knob Lick granite.

Dark spots, known locally as "knots," occur in many of the quarries, being especially abundant in the gray granite, making it unfit for either monumental or constructional work. These knots vary from a fraction of an inch to a foot or more in cross section and are usually finer grained than the granite. The chief constituent is biotite which makes the spots much darker than the matrix.

Vertical or inclined veins of fine grained red granite, known as porphyry seams occur in a number of the quarries. They are either vertical or inclined.

Vertical and inclined joints occur in all the quarries, usually in such a manner as to permit the quarrying of blocks of dimensions suitable for buildings. The granite contains dries, which injure considerable stone,

part of the output is rough stock for monuments and buildings. Since 1889, owing to labor difficulties, very little attention has been given to finished work.

A partial list of the buildings and monuments in which this stone has been used will be found at the close of this chapter.

RÉSUMÉ.

The granite in this area has the deepest red color of any in the State. Both in texture and color, it is very uniform in all the quarries and throughout the area. Granite blocks for any purpose and of any desired dimensions can be obtained. The size of the blocks is limited only by the carrying capacity of the derricks. For monuments this granite is very popular and is shipped to practically every State in the Union, including those in New England where an abundance of excellent granite is quarried. Monuments, in which the die is Missouri red granite, and the cap and base a light gray eastern granite, are frequently constructed. This makes a very attractive combination.

The granite takes an excellent rock faced finish and when alternated with polished courses in the walls of buildings it has a striking appearance. It takes an excellent and lasting polish.

Up to 1889, these quarries did a very large business in cut stone work, but in that year the employees went out on a strike, since which time a comparatively small amount of the stone has been cut or polished.

The first granite paving blocks used in St. Louis were furnised by Phillip Schneider, about 1877, and were laid at the end of the Third street bridge. Since that time, these quarries have produced millions of paving blocks, which have been used chiefly in St. Louis. The partially decomposed boulders, lying upon the surface, were the first to be used. These were comparatively soft and proved very unsatisfactory. At present, none but the fresh, unaltered granite is used. Comparatively few blocks are now being made. Flagging and curbing have been produced to a considerable extent and used in St. Louis. For these purposes it is very durable, being practically indestructible.

Although only three quarries are operated in this area, there are, in the immediate vicinity of Graniteville, excellent locations for new quarries. Just south of the Schneider quarry, there is a large outcrop of excellent granite, in which the stone apparently occurs in large rectangular blocks. At the so-called "Buzzard's roost," between the Syenite and Schneider quarries (See Plate VIII.), there is a knob containing an almost unlimited quantity of excellent granite. West of Graniteville, in the vicinity of "Elephant Rock," there are excellent opportunities for quarrying.

The area covered by the large surface boulders has been wisely protected from the quarryman, and these most excellent illustrations of the sub-aereal decomposition of granite have not been molested.

The following list contains the names and locations of some of the important buildings, which have been, wholly or in part, built out of granite from this area. The dimensions of some of the large pieces of granite quarried are also given, affording one an idea of the size of the blocks that may be quarried.

Traction Building, Cincinnati, Ohio, Fifth and Walnut.
Lindell Building, St. Louis, Fourteenth and Washington.
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Equitable Building, St. Louis, Sixth and Locust.
Eads Bridge, St. Louis, Piers.
Merchants' Bridge, St. Louis, Piers.
Benton Monument, St. Louis.
Star King Monument, San Francisco.
Twelve Polished Columns 16 ft. long, 2 ft. 2 in. diam, Flood Building, San Francisco.
New Washington University Buildings, St. Louis.
St. Charles Hotel, New Orleans.
John F. Davis, residence, St. Louis, Westmoreland Place.
Custom House, Memphis, Tenn.
State House, Springfield, Ill.
Commercial Building, St. Louis, Mo.
Rosenheim Building, St. Louis, Mo.
Liggett & Meyer's Building, St. Louis, Mo.
Fagin Building, St. Louis, Mo.
Merchants' Bridge and Terminal Railway, St. Louis, Mo.
Security Building, St. Louis, Mo.
Inlet Tower, St. Louis Water Works, St. Louis, Mo.
Anheuser-Busch Brewery Buildings, St. Louis, Mo.
Odd Fellows Hall, St. Louis, Mo.
Mercantile Library Building, St. Louis, Mo.
Vandergriff Building, Pittsburg, Pa.
F. E. Knowles & Co., San Francisco, Cal.
Paxton Building, Omaha, Neb.
Indianapolis Union Depot, Indianapolis, Ind.
Society for Savings Building, Cleveland, Ohio.
Blatz & Krebs, Louisville, Ky.
Henry U. Krankel, Louisville, Ky.
Thos. Allen Monument 42 tons in one piece, Pittsfield, Mass
U. S. Custom House and Post Office, St. Louis, Mo.
New City Hall, St. Louis, Mo.
U. S. Custom House and Post Office, Cincinnati, Ohio.
Marshall-Field Building, Chicago, Ill.
The Rookery, Chicago, Ill.
The Rialto, Chicago, Ill.
Studebaker Building, Chicago, Ill.
Monadnock Building, Chicago, Ill.
Kearsarge Building, Chicago, Ill.
Whitney National Bank, New Orleans, La.
Art Museum, Cincinnati, Ohio.
First National Bank, Cincinnati, Ohio.
New City Hall Extension, Cincinnati, Ohio.
Oriental Hotel, Dallas, Texas.
Central Savings Bank, Baltimore, Md.
Keith & Perry Building, Kansas City, Mo.

which might otherwise be suitable for dimensional or monumental stock. These seams frequently occur from one to three inches apart and often run in definite zones, either vertically or slightly inclined.

The chief products of the quarries in this area are monumental and dimensional stock, paving blocks, curbing, crushed granite and spalls. The following quarries were examined: The Asplof quarry, the Hill-O'Mera Construcion Co.'s quarry, the Milne and Gordon quarry, the Heman Construction Co.'s quarry, the Missouri Granite Construction Co.'s quarry, the Western Granite Co.'s quarry, the Zeran Gregory Granite Co.'s quarry, and the Alexander and Burks quarry. The small quarries, known as "motions," at Bee Knob, should probably be included in this area, although described on another page under a separate heading.

THE ALEXANDER & BURKS' QUARRY.

In 1900 Mr. Corbin Alexander of Farmington erected a crushing plant in sec. 29, T. 35, R. 6 E., east of the Hill-O'Mera Construction Company's quarry. In 1903, Mr. Burks purchased an interest in the plant and it is now operated under the firm name of Alexander & Burks. The entire output is crushed rock, which is used mainly for cement walks and macadam in St. Louis.

The stone has been quarried from six different openings, two east, one northwest, one southwest and two south of the crushing plant. They are all shallow, irregular openings, having a vertical face of only a few feet. The stone, in general, is badly decomposed and fit only for crushing. In parts of some of the openings the stone is practically decomposed into a coarse sand. The openings, in general, have from two to six feet of stripping, the stone being quarried where it can be obtained with least expense. The color varies in the different openings from a light to a deep red. The texture is very similar to that of the granite in the Hill-O'Mera quarry. It is so badly decomposed that it is worthless for dimensional or monumental purposes. Numerous joints which strike in various directions break the stone into small blocks.

The crusher is located on the Hill-O'Mera switch and the rock is hauled to it by wagon from the openings. Each quarryman is paid according to the amount of stone which he delivers at the crusher.

THE ASPLOF QUARRY.

This quarry, which is operated by A. J. Asplof, is located about half a mile west of Knob Lick, on land owned by Edward Price. It consists of an irregular opening 150 feet east and west and 100 feet north and south. The face is from fifteen to twenty feet in height and is covered with from three to six feet of stripping.

The granite is the gray variety and consists essentially of feldspar, quartz and biotite. The quartz is less abundant and the biotite more abundant than in the red varieties. The feldspar is chiefly white, although there is an occasional pinkish colored individual. When viewed at a distance, the granite has a dark bluish tint, on account of which it is known locally as blue granite. It has a finer texture than the red granite.

In some places the biotite has segregated into knots which have a much darker color than the body of the granite, destroying its value for monumental or building purposes. It is seldom possible to obtain a large block which is free from these segregations. Yellowish red streaks, due to an increase in the red or pink feldspar, occur parallel to the so-called bedding. Fine black seams are also common.

In the gray granite, the rift is approximately north and south, while in the red granite it is about east and west. In the gray granite, the lift is the hard way to work the stone, while in the red granite the hard way is at right angles to the rift and lift. The gray granite splits with a smooth fracture and is easier to work into blocks than the red granite. The larger knots sometimes draw the fracture producing an uneven surface. Two-inch cubes of this granite gave a crushing strength of 18,234 pounds per square inch.

The entire output is cut into paving blocks. The stripping and spalls have been thrown into the quarry, making it difficult to work. When visited in November, 1903, seven paving block cutters were employed.

THE HILL-O'MERA CONSTRUCTION COMPANY'S QUARRY.

The Hill-O'Mera Construction Company of St. Louis owns a large quarry located in sec. 30, T. 35, R. 6 E. This quarry is not active at present, but at one time it was a large producer. It has been worked 160 feet north and south and 110 feet east and west, and has a vertical face of from ten to thirty feet. Near the middle of the west face a gully at the surface reduces the exposure to about ten feet. Along the west and the south central portions of the east face the granite is flanked by sandstone. Beneath this the granite is decomposed to a depth of from three to five feet.

The granite has a uniform light red color, very similar to that from portions of the Milne and Gordon quarry. It has the usual texture of the red granite of this district and is composed mainly of feldspar, quartz and mica.

The major joints strike N. 80°-85° W. and dip 11° N. 10°-15° E. At the north end of the quarry they are the following distances apart: 15 ft. 8 in.; 1 ft.; 6 ft. 8 in.; 1 ft. 10 in.; 1 ft. 10 in.; 7 ft.; 13 ft.; 4 ft.

RED GRANITE.
Quarry of Milne and Gordon, Syenite, Mo.

These joints permit the quarrying of blocks of very large dimensions. Occasional inclined joints intercept the quarry face at an angle of about 45°. At the south end the face is solid granite, showing no horizontal joints. At the north end bedding planes occur from two to six feet apart.

A number of red and brown seams angle through the face, especially at the north end of the quarry, spoiling considerable of the stone for dimensional purposes. A diabase dike, about two inches in thickness, at the bottom, occurs at the south end of the quarry.

The stone has a well developed lift and rift. The rift is practically parallel to the major joints, N. 80°-85° E., while the lift is nearly horizontal. The head or "hardway" of the stone is at right angles to these two.

The quarry is connected by a spur with the St. Louis, Iron Mountain and Southern railroad. The equipment consists of a large cutting shed, derrick, steam hoist, engine, boilers and such other implements and tools as are necessary for working the granite.

The output has consisted of curbing, paving blocks and dimensional stone. During the last few years the quarry has only been worked in a small way.

THE MILNE & GORDON QUARRY.

Milne and Gordon own and operate a quarry located one mile west of Knob Lick, in the N. W. ¼ of the S. E. ¼ of sec. 5, T. 34, R. 6 E. This quarry, which was opened in 1874, is near Syenite, being the first extensive quarry at that place.

Two hundred and ten feet of the face is along a major joint, which strikes N. 70° W. The remainder of the face extends 240 feet north and south. The height of the face is approximately sixty feet.

The granite is the typical red, Syenite variety. The principal constituents are quartz, feldspar, biotite and a small amount of hornblende. The quartz is not nearly so abundant a constituent as in the Graniteville granite and is generally translucent or slightly smoky. Feldspar, of the orthoclase variety, is the most abundant constituent and varies in color from white to red. The black biotite is an essential constituent and is more abundant than in the Graniteville granite. It is medium grained, being somewhat finer than the Graniteville granite. The individuals are intricately interlocked giving it both strength and durability.

The color varies from a pinkish gray to a somewhat deep red. The color is considerably lighter than that of the Graniteville granite and the color varies slightly in different parts of the quarry. Near the bottom

of the quarry, at the east end, there is a streak having an unusually deep red color. Occasional segregations of biotite, or hornblende, known as knots, occur in the stone. They vary from a fraction of an inch to several inches in cross section. These knots are less abundant than in other quarries of the Knob Lick district.

The major joints strike N. 62° to N. 75° W. The most prominent are from twenty to thirty feet apart, with minor ones between. The joints of another set, which strikes at right angles to this, are far apart. There are two prominent bedding planes, which dip from 20° to 30° northeast into the hill. They assist very greatly in quarrying the stone. The beds are thinner to the south near the natural outcrop. The upper bed has been almost entirely removed, the stone now being taken from the second bed. Plate XI. shows a very large block of granite, which has been removed a few feet from the quarry face and is now being broken into large dimension blocks. This also illustrates how a combination of vertical and horizontal joints may facilitate quarrying. The lowest portion of the north end of the quarry shows no bedding planes beneath those already mentioned.

Occasional dark colored, tight seams in the granite occasion considerable waste. Some stone, which would otherwise make excellent monumental stock, is injured by small dries. These seams are parallel to one another, an inch or two apart, and either vertical or slightly inclined. The blocks which contain these seams are, for the most part, unfit for anything except paving blocks or crushed stone.

The east half of the quarry is covered with about ten feet of stripping, while the west part is a bald outcrop. The stone which is overlain with stripping is inferior and therefore not being quarried. Along the joints the feldspar has decomposed, leaving a residuum of yellowish white kaolin. This decomposition has not extended very far into the stone.

This granite takes an excellent polish, but the contrast in color between the hammered and polished surfaces is not very strong. Two-inch cubes of this granite gave a crushing strength of 22,882 pounds per square inch.

The quarry is connected with the St. Louis, Iron Mountain and Southern railroad by a gravity tram. The loaded cars are hauled up the hill east of the quarry by cable, beyond which the track is down grade the entire distance to Knob Lick. The quarry and polishing sheds are equipped with steam power which operates three large derricks, hoists, drills and polishers. The principal products of the quarry are monumental and dimensional stock. The stone which is unfit for these purposes is worked into paving blocks. The spalls from the quarry are shipped to

St. Louis. Dimensional blocks of excellent quality are obtained at this quarry.

THE MISSOURI GRANITE CONSTRUCTION COMPANY'S QUARRY.

This quarry is located in the N. W. ¼ of sec. 17, T. 34, R. 6 E., about three miles from the St. Louis, Iron Mountain and Southern railroad, with which it is connected by a spur. It was opened about six years ago and consists of two openings, one northwest and the other southeast of the crushing plant.

The following are the officers of this company: Mr. Leo. Schmaltz, president; Mr. M. Sullivan, secretary, and Mr. J. R. Quinley, superintendent. The general offices are in St. Louis.

Most of the stone has been quarried from the southeast opening, which has an irregular triangular shape about 100 feet on a side and from thirty to thirty-five feet in depth.

One horizontal joint occurs from ten to twenty feet below the surface of this opening. The joints strike in various directions. They are quite abundant in some parts of the quarry, breaking the stone into comparatively small blocks. A number of these joints strike N. 45° E., east and west, N. 30° W. and N. 35° E. Along these seams the stone usually has a black color.

The granite was first quarried along a five-foot diabase dike, striking N. 48° E. West of this dike, the face is intercepted by frequent horizontal joints.

The east face contains a twelve-inch dike of very red, fine grained granite, in which feldspar predominates. A number of similar, smaller streaks occur at the west end of the quarry. They injure the stone for monumental or building purposes.

The stone also contains occasional series of short, tight seams which injure it for monumental or building purposes. These are most abundant in the southeastern part of the quarry where there are very few major joints.

The opening northwest of the crushing plant had not been worked long when the quarry was inspected. It will have a 200-foot face and it is intended to connect it with another small opening which was worked several years ago. The granite is very similar in color and texture to that in the southeast opening.

The major joints strike N. 55° E. and N. 45° W. The latter are from two to ten feet apart. Close to the crushing plant, where the opening has been worked to a depth of twenty feet, it shows bedding planes 4½, 6 and 8 feet apart. Dark seams and dries occur as in the southeast opening.

A large part of the stone is crushed, only the best being used for building or monumental purposes. Some paving blocks are manufactured.

The equipment consists, in part, of one railroad locomotive, two steam hoists, two derricks, three steam drills, stationary engine, boiler and three crushers, Nos. 1, 3 and 5.

This is one of the largest granite crushing plants in the State. After crushing, the stone is screened into several different sizes which go directly to large storage bins of about 1,000 tons capacity. The crushed stone is loaded, by means of chutes, directly from the bins into the cars.

THE WESTERN GRANITE COMPANY'S QUARRY.

This quarry is located about three-fourths of a mile southwest of Knob Lick. It has been opened for a distance of about 150 feet along the major jointing planes which strike N. 40° W. It has also been opened at right angles to this direction for a distance of 65 feet. At the east end, where it is now being operated, the face is 45 feet high.

The granite consists essentially of pink and white feldspar, quartz and biotite. The color is a grayish pink, lighter than the granite at Milne and Gordon's quarry. Occasional dark, roundish or oval spots, known as knots, occur in the granite. These are segregations of biotite similar to those described in connection with other quarries in the district. They are injurious to stone used for monumental or building purposes, but for crushing they are not especially detrimental.

The major joints strike N. 40° W. and minor joints N. 45° E. The stone also contains dries. The joints are numerous, but in places large dimensions might be obtained. The dark spots and dries, however, are too abundant to admit the quarrying of large quantites of this stock.

The crusher is connected by side track with the St. Louis, Iron Mountain and Southern railroad. The stone is hauled from the quarry to the crusher by wagon. Crushed stone is the chief product, although paving blocks and dimensional stone are produced to a small extent.

THE ZERAN GREGORY GRANITE COMPANY'S QUARRY.

The Zeran Gregory Granite Co., of Cairo, Illinois, has opened a quarry in sec. 35, T. 35, R. 5 E., on the farm of Mr. Gregory. When visited the quarry had just been opened and the granite was exposed only to a depth of twelve feet between two jointing planes, covering an area about eight feet by forty feet. The natural outcrop of granite covers an area of about 22,500 square feet. West of this exposure small boulders of granite occur at the surface, indicating that the stripping in that direction is not heavy.

This granite consists essentially of feldspar, quartz and mica. As

far as exposed the granite has a uniform, deeper red color than most of the granite in this area. It takes an excellent polish and is very hard. It breaks with a very straight fracture.

The major joints, which strike N. 65° E. and are from three to ten feet apart, break the stone into large dimensional blocks, that can be easily quarried. The minor joints, which strike at right angles to the major set, are very few in number, only one showing near the middle of the face.

The granite contains an occasional dark seam, similar to those in other quarries of this area. A number of parallel dries occur in the upper part of the quarry. As elsewhere these imperfections in the stone cause considerable waste.

The chief product is monumental stone which is shipped to Cairo, Illinois. The quarry is two miles from the Turpin switch, to which the stone must be hauled by team.

PIEDMONT.

When the paving block industry was at its height in this district, two quarries were opened in the rhyolite north of Piedmont. Neither of these quarries has been worked during the last ten years. They were formerly operated by Eyerman and Schmaltz of St. Louis, and Sheahan Bros. They illustrate very well the character of the rhyolite (porphyry) of this district.

The rhyolite at these two quarries is very similar, both in texture and color. It consists of a fine grained, black ground-mass through which are disseminated numerous gray and white crystals of feldspar, giving the stone a mottled appearance. These porphyritic crystals vary in size from minute white dots to those which are a half an inch in diameter. The blending of the black ground-mass with the white feldspar crystals gives the stone a grayish black color.

The joints are very abundant in both quarries and strike in many different directions. The following is the strike of a number of the more prominent: N. 70° E., N. 33° W., N. 30° E., N. 40° W., N. and S. and N. 80° E. Many of these joints are vertical, while others are inclined at different angles. Horizontal joints having a slight dip to the south occur from three to ten feet apart.

The frequency with which these joints occur, together with the diversity in their strike and dip, break the stone into comparatively small blocks. It is practically impossible to obtain blocks sufficiently large for either dimensional or monumental stock. The jointing greatly facilitates the quarrying of small blocks and is therefore of assistance in the manu-

facture of paving blocks or crushed stone. The stone for about a half an inch on either side of many of the joints is weathered to a light gray or pink.

This stone has been used chiefly for the manufacture of paving blocks. It wears smoother and is claimed to be more slippery than the granite, and for these reasons is said to be less desirable. The rhyolite is thought to be well adapted to the manufacture of crushed stone used in macadam pavements or granitoid walks.

THE EYERMAN & SCHMALTZ QUARRY.

This quarry is located two miles north of Piedmont and is situated on the south side of a rhyolite knob. The quarry consists of an irregular opening having a face 150 feet east and west and 175 feet north and south. The total depth of the face is 70 feet, the floor of the quarry having about the same slope as the hillside. At the time the quarry was inspected, it contained great quantities of broken stone suitable for crushing.

THE SHEAHAN BROS. QUARRY.

This quarry is located in sec. 23, T. 29, R. 3 E., on land owned by T. A. Johnson of Piedmont. The quarry consists of an opening having an east and west face of 200 feet and a north and south face of 250 feet. The face is about thirty feet in height. The quarry contains a great quantity of spalls which, when crushed, would make an excellent road metal.

VAN BUREN.

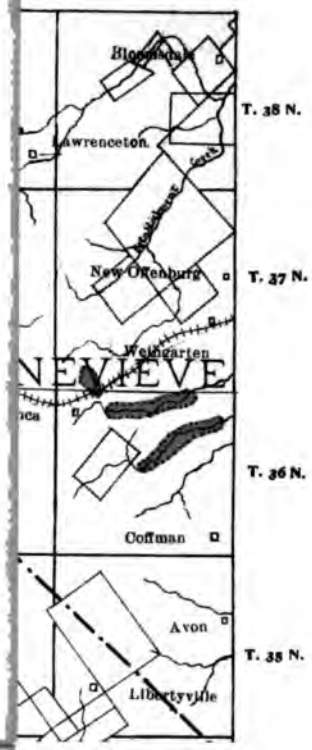
THE CURRENT RIVER GRANITE CO.'S QUARRY.

This company, consisting of Alex. Carter and James McGee, opened a quarry in 1894 in the S. W. ¼ of the S. E. ¼ and the S. E. ¼ of the S. W. ¼ of sec. 29, T. 27, R. 1 E., on the east side of Current river. The quarry has not been operated for a number of years.

It is situated on the west side of a roundish granite knob which rises about 120 feet above the level of the river. The granite is flanked on all sides by limestone which rises on the east about 150 feet above the granite. The face occupies almost the entire length of the hill and has a maximum height of thirty feet.

The granite is fine grained and consists chiefly of feldspar, quartz and biotite. The color is several shades of red, the darkest being near the base.

The joints are numerous and strike in many directions. The more important strike N. 40° W., N. 65° W. and N. 50° E.



MISSOURI BUREAU OF GEOLOGY AND MINES.

E. R. BUCKLEY, Director.

MAP

SHOWING THE DISTRIBUTION OF

QUARRIES

IN THE

GRANITE DISTRICT OF SOUTHEAST MISSOURI,

BY

H. A. BUEHLER.

1904.

Geology based upon map by ERASMUS HAWORTH in Vol. VIII of the Missouri Geological Survey Reports.

Crushed granite and paving blocks were the principal products of this quarry, and were shipped chiefly to Kansas City and St. Joseph, Missouri, and Memphis, Tennessee. The quarry is equipped with a crushing plant, consisting of a No. 4 Gates crusher, rotary screens and other accessories. It was formerly connected by spur with the Kansas City, Ft. Scott and Memphis branch of the St. Louis and San Francisco railroad.

CHAPTER VI.

CAMBRO-ORDOVICIAN.

The southern part of the State is largely underlain with a series of sandstone and magnesian limestone formations. Four different limestone and three different sandstone formations have been recognized as belonging to either the Cambrian or Ordovician, or perhaps to both, of these groups. The stone varies greatly in different parts of the several formations and nowhere have extensive quarries been opened. Much of the stone is adapted to use in buildings and other constructions, but very little of that which is durable can be cut and dressed satisfactorily.

There are hundreds of places in the area underlain by these rocks from which small amounts of stone have been quarried. It would be practically impossible to locate and examine all these small quarries. It has therefore been our purpose chiefly to describe the stone as it occurs in some of the larger quarries, knowing that these descriptions apply very generally to the stone from the same horizons in other localities. The limestone quarries are described in the first part of the chapter and the sandstone quarries in the second part.

PART I. DOLOMITE (LIMESTONE).

BOLIVAR.

Two quarries, owned by John W. McReynolds and R. B. Vilas, are located in the vicinity of this city. The quarries are small, the stone being used exclusively to supply the local market. The stone is argillaceous, arenaceous dolomite, known as cotton rock, and pitted dolomite belonging to the Jefferson City formation. A great many other small quarries have been opened in this vicinity, but they are not being operated at present.

THE McREYNOLDS QUARRY.

This quarry, which is located one mile east of the city, has a face 200 feet long and 8 feet high. The stone is a fine grained, compact, light gray, magnesian limestone, in beds from two to sixteen inches in thickness. It contains small flecks or nodules of iron oxide. The upper layers

are broken into small pieces by short vertical joints. The stone is easily quarried, cut and dressed, but apparently does not withstand the weather.

THE VILAS QUARRY.

This quarry is located near the southeast limits of the city. It has a west face 85 feet long. The principal bed is 32 inches thick and consists of siliceous, magnesian, pitted, limestone. It has a dark gray color, is finely crystalline and contains cavities filled with granular white quartz, which gives the stone a mottled appearance. There is a bedding plane four inches from the top, the remainder being solid. In working this bed, it is usually split into two layers of equal thickness. Cotton rock occurs below this, but it is not quarried. It is overlain with three feet of light gray, fine grained cotton rock. It occurs in layers from two to six inches in thickness and is used only in unexposed portions of the walls. The stone from the thick mottled bed was used in the foundation of the new wing of the Bolivar Southwestern Baptist College.

DE SOTO.

THE FRECH QUARRY.

This quarry, which is owned and operated by A. L. Frech, is located near the west limits of the city. It is situated near the top of a hill and the aggregate length of the face is about 1,100 feet. It is now being worked near the south end. The stone is typical cotton rock and is used locally for foundations and rough masonry. The bedding planes are smooth and the stone is easily quarried. The following is a description of the beds from top to bottom:

2 ft.	Soil and clay stripping.
3 ft.	Yellowish gray limestone; splits into four beds.
3 ft.-3 ft. 6 in.	White and brown limestone. The white portion varies from one foot to three feet in thickness. A layer of flint two to six inches in thickness occurs at the top of the bed. Contains many dries.
1 ft. 6 in.-2 ft. 3 in.	White, fine grained limestone, containing small quartz geodes. Dries occur in this bed.
0-1 ft.	Light gray, fine grained, hard limestone.
1 ft. 6 in.	Fine grained, light gray limestone. Splits into two layers seven inches from the top. In some places this bedding plane is absent.
1 ft. 3 in.	Cotton rock, similar to the above. Contains a number of thin shaly seams. Splits into layers five inches in thickness. Used for ashler blocks, sills and caps.

The beds vary in thickness in different parts of the quarry and are separated from each other by thin seams of shale. The major joints strike N. 65° W. and are from two to twelve feet apart. They dip 10° S. In some places they are very close together, breaking the stone into blocks too small for constructional purposes. Minor joints strike at

right angles to the major. They are few in number and frequently do not continue through more than two or three beds.

When first quarried, the stone has a very light color, but after long exposure it takes on a yellowish gray tint due to oxidation of the iron sulphide. The stone works well, breaking with an even fracture. The smooth bedding planes obviate the necessity of dressing the stone on two sides. It spalls with a splintery conchoidal fracture.

Most of the stone is used locally for ashler masonry, foundations and cemetery work. A small quantity has been shipped to Ironton.

LABORATORY EXAMINATION.

Chemical Aanalysis.—The following is a chemical analysis of a sample of cotton rock from the quarry of A. L. Frech:

Insoluble	11.19
Fe_2O_3, Al_2O_3	.68
$CaCO_3$	48.18
$MgCO_3$	39.99
Total	100.04

Physical Tests.—Two-inch cubes of the cotton rock from this quarry were subjected to a series of physical tests with the following results:

Specific Gravity	2.706
Porosity	6.717%
Ratio of Absorption	2.603
Weight per cubic foot	161.2 lbs.
Transverse strength	2219.5 lbs. per sq. in.
Tensile strength	9831. lbs. per sq. in.
Crushing strength	17,834. lbs. per sq. in. on bed. 15,074. lbs. per sq. in. on edge.
Crushing strength of sample subjected to freezing test	16,880

From the above it will be observed that the samples subjected to the freezing test lost on an average of 954 pounds per square inch.

ELDON.

THE SHUTT IMPROVEMENT CO.'S QUARRY.

This quarry, which is located three miles east of the city, on the St. Louis, Kansas City and Colorado railroad, has been opened for the production of railroad ballast. The company has only recently started operations at this place and has not developed a very extensive working face. The quarry consists of an opening approximately fifty feet on a side. It is situated on a hill which contains an inexhaustible supply of stone.

The face is twenty feet high and the lower half consists of typical Jefferson City (Second Magnesian) limestone. It is a finely crystalline stone, containing small irregular cavities filled with granular quartz. The

stone in the upper ten feet has a gray to buff color and is not mottled like that in the lower part.

The crushing plant, which is located at the quarry, is equipped with two Gates crushers, Nos. 4 and 7½, a two-foot bucket elevator, screens, boilers and engine. A large quantity of stone can be produced at this place.

ELSTON.

Two small quarries are located two and one-half miles west of Elston and one-fourth of a mile north of the Missouri Pacific railway. These quarries are owned by Mr. Wm. Hitch and Mr. L. Wade.

THE HITCH QUARRY.

This quarry is located in the N. W. ¼ of the N. E. ¼, sec. 28, T. 45, R. 13 W. It has a face thirty feet long and consists of two beds of magnesian limestone. These beds are covered with three feet of soil stripping. The stone contains irregular cavities filled with a white granular quartz which weathers out, leaving the surface rough and hackly. The beds are ten and fourteen inches in thickness and contain good stone for foundation purposes.

THE WADE QUARRY.

This quarry, which is a short distance north of the Hitch quarry, has a face of thirty-five feet and consists of seven beds from four to fourteen inches in thickness. The thickest beds are at the bottom. The stone is a light gray, fine grained cotton rock containing small drusy cavities. Along the bedding and joint planes the stone is a buff color. It has been used exclusively for foundations.

FARMINGTON.

The principal quarries near this city are operated by E. K. Hawn, Geo. Haller, J. B. Mueller & Son and the State Hospital for the Insane.

THE HAWN QUARRY.

This quarry, which is located near the northeast limits of the city, consists of an irregular circular opening, having a diameter of 200 feet and a maximum vertical face of 15 feet. The quarry was opened in 1900 and has been operated each year to supply the local market.

There is very little difference in the stone from different parts of the quarry. It is a fine grained, blue, magnesian limestone, occurring in beds from two to eighteen inches in thickness. Along the joints it has a buff color. When exposed to the atmosphere it takes on a lighter tint.

The heavier beds contain thin shaly seams, along which they split very readily. The stone contains small crystals of disseminated pyrite and calcite. The beds dip gently in all directions from the center of the quarry.

The joints strike in many different directions. Those which have been cemented with calcite strike north and south, while others strike N. 60° E., N. 70° E., N. 80° W., N. 5° W. and N. 20° W. The N. 20° W., joints are from three to five feet apart at the east end of the quarry and dip 16° S. W. Near the middle, there are two gentle monoclinal folds, the axes of which strike N. 10° W. In the northeast corner, there is a circular area, separated from the remainder of the rock by curved joints, in which the rock is too hard for building stone.

The stone is used chiefly for rough masonry and pavements. A small amount has been shipped to Oran. From six to ten men are employed in the quarry during the summer months.

THE HALLER QUARRY.

This quarry is just north of the Hawn quarry and the stone is practically the same, being a magnesian limestone. It occurs in thin beds and is used chiefly for foundations and road construction.

THE MUELLER & SON QUARRY.

This quarry, which is located a half a mile east of the city limits, is situated along a ravine and has a face 800 feet long and from six to ten feet high. It has been worked intermittently since 1899.

The north end consists of three feet of red clay stripping, six feet of bluish gray, fine grained limestone and six inches of shale. Directly beneath the stripping and along the bedding planes the stone has a buff color. At the south end the beds are thin, dip gently to the southeast, and have a deep blue color.

The major joints strike N. 8° E. and are from six to twenty feet apart. Advantage is taken of them in quarrying. The stone is used locally for foundations and road construction.

THE STATE HOSPITAL QUARRY.

This quarry, which is located just east of the road from the main entrance to the buildings, has furnished stone for the foundations to the Hospital buildings. It consists of a semi-circular opening, having a face 250 feet long. The stripping consists of about three feet of red clay underneath which are beds 3 ft. 6 in., 3 ft. and 1 ft. 6. in. in thickness. The stone is a fine grained, bluish gray, semi-crystalline, magnesian limestone. The uppermost bed contains small hackly cavities. As a

whole, the beds are thicker and better adapted for constructional work than those at the other quarries. It is expected to install a crushing plant to provide stone suitable for macadamizing the asylum driveways.

FREDERICKTOWN.

THE DAVIS QUARRY.

This quarry, which is owned and operated by R. N. Davis, is located on the northwest side of a hill, one and one-half miles west of Fredericktown. It has been operated since 1894 and has a face of 150 feet. The following is a description of the beds from the top to the bottom:

3 ft.	Red clay stripping.
1 ft. 7 in.	Bluish gray, fine grained, compact limestone. Badly broken by joints.
1 ft. 8 in.	Dark blue, fine grained limestone, containing drieg.
8 in.	Light blue, argillaceous limestone. Very shelly.
2 ft.	Fine grained limestone. Upper six inches has a mottled gray color. Lower portion is blue and shelly.
1 ft. 6 in.	Somewhat mottled, bluish colored limestone. The middle of the bed contains a six inch layer of dark colored limestone.

The beds in this quarry dip slightly to the south and are badly broken with joints which strike N. 58° W. At the east end, six feet of stone is quarried above the beds described in the section. This stone occurs in beds from six to twelve inches in thickness and is interstratified with thin layers of shale.

The quarry is operated from March 1st to December 1st and employs four men who work with hand tools and a horse power derrick.

The stone from this quarry has been used in the Marvin Collegiate Institute and Dormitory and in the new courthouse at Fredericktown. It has been shipped to Charleston, Bertrand and Silverton, Missouri.

HEMATITE.

THE GRAY QUARRY.

This quarry is located one-fourth of a mile south of the town and is situated on the south side of a hill just west of the St. Louis, Iron Mountain and Southern railroad. It was opened in 1894 by E. O. Orleans and is now owned by Mr. L. M. Gray of St. Louis and operated by John Caskanett of Hematite.

The quarry has been worked into the hill from twenty to forty feet and has a face 240 feet long. The stone is a typical, fine grained cotton rock, similar to that at DeSoto. When first quarried it is nearly white, but upon exposure it gradually changes to a yellowish buff color, especially

along the fine stratification planes. The following is a description of the beds from top to bottom:

1 ft.	Soil stripping.
2-4 ft.	White, fine grained cotton rock. Separates into three or four beds. Stone is too soft to be used.
8 ft.	Cotton rock can be split as desired, usually into three or four layers. The stone is rather soft and contains fine stratification planes about two inches apart.
1 ft. 1 in.	Cotton rock, containing occasional crystals of pyrite. The stratification planes are not as abundant as in the upper beds. This bed can be capped five inches from the top. This is the strongest and best stone in the quarry.
10 in.	Cotton rock containing fine stratification planes one to two inches apart.
10 in.	Solid bed of cotton rock, varying somewhat in thickness. At the east end, this bed is eight inches thick.
1 ft.	Fine grained cotton rock containing thin shaly seams, especially near the top. The upper three inches is shelly and the lower nine inches solid.

The major joints are not abundant. They have a general east and west strike. Near the west end of the quarry, there are minor joints which strike N. 50° W. and have a dip of 10° to the southwest. The stone is exceptionally free from dries which occasion so much waste in other quarries. They occur chiefly in the surface stone. Near the east end the stone is flinty and for this reason it is quarried chiefly at the west end.

Underneath the floor the stone has a bluish color, is very soft and is known locally as "cement rock." It has been used for curbing, but owing to the stratification planes it is unfit for this purpose.

The entire output is manufactured into sewer caps, which are shipped to St. Louis. These caps are 4 feet x 5 feet x 8 inches in size. They are dressed square and have a man-hole in the center. With each of these caps are two keystones and a sill five feet long and one foot square. A royalty of 50 cents is paid on each stone quarried. The freight rate from Hematite to St. Louis is $1.00 per stone and the price delivered in St. Louis is from $7.00 to $7.50 each. From twenty to thirty stones are produced each month.

Just west of this quarry is an old opening which was operated about fifteen years ago. The beds are below those in the quarry above described, and the stone is a fine grained, soft, blue cotton rock not suitable for constructional purposes.

JEFFERSON CITY.

All of the stone quarried in this vicinity belongs to what is known as the Jefferson City (Second Magnesian) limestone. This formation con-

1.

2.

DOLOMITE (JEFFERSON CITY).

Fig. 1. Cotton rock, penitentiary wall, Jefferson City, Mo.
Fig. 2. Portion of a cotton rock quarry, Jefferson City, Mo.

sists of two divisions, an upper which is chiefly cotton rock and a lower which is thickly bedded, pitted limestone. The cotton rock occurs in clean cut, well defined beds, which are easily quarried. It is fine grained, impure, light gray to buff colored, dolomitic limestone, which is easy to cut and dress, and looks well when placed in a wall. It has been used very extensively in Jefferson City and can be seen in the wall surrounding the penitentiary, in the retaining walls around the Governor's mansion and in many of the buildings.

The pitted dolomite occurs in thicker beds than the cotton rock and contains irregular cavities filled or lined with fine sugary quartz. It has been used in a number of important buildings, although it is not quarried at present, except for the manufacture of quick lime. A three-foot bed occurs with the cotton rock in nearly all the quarries.

The quarries located in this vicinity are owned and operated by John Dietz, John Kieselbach, Mueller & Geisler, The City, The State, Jacob Schmidt, Hagner and Lumis and L. D. Gordon. The stone in the last two is being used exclusively for the manufacture of quick lime and will be described in a subsequent report on "Lime and Cement."

THE CITY QUARRY.

In connection with the workhouse, the city operates a small quarry at the foot of Madison street adjacent to the tracks of the Missouri Pacific railroad. The following is a description of the beds from the top to the bottom of the quarry:

10 ft.	Red clay stripping.
10-12 ft.	Fine grained, light gray limestone, in beds from two to eight inches in thickness. The stone in the upper two feet is very shelly. Contains numerous vertical joints which break the stone into small blocks.
1 ft. 8 in.	Fine grained, gray limestone, containing small cavities.
1 ft. 2 in.	Two beds of limestone, very similar to that above.
1 ft. 6 in.-2 ft.	Dark gray, pitted, magnesian limestone. Contains irregular cavities filled with siliceous material.
1 ft. 6 in.	Gray, oölitic limestone, containing considerable chert.
1 ft. 2 in..-2 ft.	Dark gray, cherty limestone, containing numerous joints.
5 ft. 8 in.	Fine grained, gray limestone, containing spots and streaks of iron oxide. Consists of four beds of equal thickness.

Short vertical joints break the stone into small blocks. A small amount of stone is broken by hand to be used in repairing the macadamized streets. When used alone it is too soft for macadam.

THE DIETZ QUARRY.

This quarry is located one and one-half miles east of the city and consists of three openings, none of which are being operated.

The north opening has a face about 50 feet long and consists of seven beds, aggregating eight and a half feet in thickness. The following is a description of these beds from top to bottom:

15 in. 16 in. 12 in. 15 in. 12 in. 18 in. 14 in.	This stone is a dark gray, pitted magnesian limestone. When freshly quarried, it has a spotted appearance due to small cavities filled with white, sugary quartz, which weathers out upon exposure leaving a rough, hackly surface.

A number of these beds can be split into thinner layers. Quarrying has not extended very far into the hill and the bedding planes are free and open. Rectangular blocks of almost any dimensions can be obtained.

In a second opening, located in a small ravine northeast of the house, the cotton rock overlying the heavy pitted dolomite is quarried exclusively. It varies from a gray to a buff color and occurs in well stratified beds containing short tight seams. The lower beds also contain irregular joints having a dip of 10° to 20°. This opening has not been worked very extensively.

The third opening, located just north of the south road, has been developed more extensively than either of the other two. It has a face about 125 feet long. The following is a description of the beds from the top to the bottom:

2-4 ft.	Chert and clay stripping.
1 ft. 2 in.	Fine grained, light gray limestone.
2 ft. 6 in.	Light gray limestone. Can be split into three beds.
6 in. 8 in. 8 in.	Well defined beds of fine grained, gray limestone.
1 ft. 6 in.	Fine grained, dark gray limestone. This is a pitted bed containing cavities filled with white sugary quartz.
6 in. to 1 ft. 6 in.	Broken cherty limestone.
2 ft.	Fine grained, bluish gray limestone, containing brown spots of iron oxide. Can be split into two 12 inch beds.
1 ft.	Light buff colored limestone, containing numerous cavities.
1 ft. 3 in.	Blue, finely stratified limestone, weathered to a buff color along the bedding planes.
2 ft. 10 in.	Fine grained, gray limestone, containing streaks of brown iron oxide along the stratification planes. Occurs in beds from four to eight inches in thickness.

The stone from this opening is chiefly a cotton rock similar to that in the other quarries. The joints are irregular and break the stone into blocks of uncertain dimensions. The beds dip gently in all directions from the middle of the opening.

THE MUELLER & GEISLER QUARRY.

This quarry is located one and one-half miles south of the city. It is situated at the base of a hill and has a north face 300 feet long. The following is a description of the beds from top to bottom:

2-4 ft.	Clay stripping.
4 ft.	Grayish white cotton rock. Is used for ashler blocks and foundations.
2 ft.	Siliceous, magnesian limestone. This bed can be split into three 8-inch layers at the west end of the quarry and into five thin beds at the east end.
1 ft. 6 in.	Dark gray flinty limestone.
10 ft.	Fine grained, light gray cotton rock, in beds from four to ten inches in thickness. The stone in the lower beds has a blue color.

The cotton rock is used in buildings in Jefferson City. The siliceous limestone has a pleasing light gray color when first quarried, but becomes much darker when exposed to the atmosphere. It is the lightest colored pitted dolomite observed in any of the quarries in this vicinity.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of both cotton rock and pitted dolomite from this quarry were examined in the laboratory with the following results:

Cotton Rock:		
Specific Gravity	2.783	
Porosity	8.574	per cent.
Ratio of Absorption	3.370	
Weight per cubic foot	153.8	lbs.
Tensile strength	970.75	lbs. per sq. in.
Transverse strength	2,949.2	lbs. per sq. in.
Crushing strength	16,672.3	lbs. per sq. in. on bed.
	16,348	lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	15,680.5	lbs. per sq. in.
Pitted Dolomite:		
Specific Gravity	2.779	
Porosity	8.312	per cent.
Ratio of Absorption	3.262	
Weight per cubic foot	154.1	lbs.
Transverse strength	1228.8	lbs. per sq. in.
Tensile strength	498.5	lbs. per sq. in.
Crushing strength	11,141.	lbs. per sq. in. on bed.
	11,356.	lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	9,640.	lbs. per sq. in.

These tests indicate that the cotton rock lost through the freezing test an average of 991.8 pounds per square inch. The pitted dolomite lost on an average of 1501 pounds per square inch.

THE KIESELBACH QUARRY.

This quarry is located near the southern limits of the city, in the N. E. ¼ of the S. E. ¼ of sec. 18, T. 44, R. 11 W. It has a north face fifty feet long and twenty-four feet in height and has been worked into the hill about thirty feet. The stone is all cotton rock, which occurs in beds from four to twelve inches in thickness. In the lower part of the quarry, the stone has a light blue color, while above it varies from a grayish buff to a light gray.

The major joints strike N. 64° E. and N. and S. Short discontinuous joints occur throughout the individual beds, breaking the stone into small blocks. Sills and foundation stone can be produced at this quarry.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of both the cotton rock and pitted dolomite were tested in the laboratory with the following results:

Cotton rock:		
Specific Gravity	2.776	
Porosity	9.248	per cent.
Ratio of Absorption	3.66	
Weight per cubic foot	157.5	lbs.
Transverse strength	2468.5	lbs. per sq. in.
Tensile strength	862.5	lbs. per sq. in.
Crushing strength	15,964.7	lbs. per sq. in. on bed.
	16,899.	lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	15,145.	lbs. per sq. in.
Pitted Dolomite:		
Specific Gravity	2.80	
Porosity	10.317%	
Ratio of Absorption	4.058%	
Weight per cubic foot	157.0	lbs.
Tensile strength	727	lbs. per sq. in.
Crushing strength	11,950	lbs. per sq. in. on bed.
	10,148	lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	11,962	lbs. per sq. in.

From the above tests it will be seen that the frozen samples of cotton rock tested on an average of 819.7 pounds per square inch less than the fresh samples, while the strength of the frozen and fresh samples of pitted dolomite were about the same.

THE SCHMIDT QUARRY.

This quarry is located just south of Atchison street near Lincoln Institute. It was opened in 1902 and has been worked intermittently since that time.

The face of the quarry consists of two twenty-four inch beds of pitted dolomite belonging to the Jefferson City (Second Magnesian)

limestone. It has a mottled color due to small irregular pockets containing fine granular quartz.

To the north, the face of the quarry increases to ten feet in height, the additional beds consisting of pitted dolomite containing considerable flint.

The stone is used to some extent for caps, sills and coursing. Formerly the State operated a quarry at a higher level on the same hill.

THE STATE QUARRY.

East of the penitentiary, the State owns a quarry which is worked by the convicts. This quarry has a west face 325 feet long and fourteen feet high. The stone is a well stratified cotton rock, which is covered with a very heavy stripping. This quarry is not worked very extensively.

The State operates another quarry west of the National cemetery. It has a face 1,000 feet long, being the largest in this vicinity. It has not been operated for some time.

The stone is typical cotton rock and occurs in well stratified beds from four to sixteen inches in thickness. The bedding planes are smooth and the beds are a very convenient size for quarrying without machinery. A bed of pitted dolomite similar to that previously described occurs near the middle of the face.

Short discontinuous joints occur in all parts of the quarry. They are confined to either one or a few successive beds. Some of these joints are inclined, especially in the lower beds. Some of those observed had the following strike and dip:

Strike.	*Dip.*
N. 35° W.	S. W. 32°
N. 55° W.	S. W. 23°
N. 55° E.	
N. 80° E.	

The beds dip gently from the middle of the quarry toward both ends.

A third quarry operated by the State, known as the "State Quarry," is located about one mile east of the city. It is situated upon a hill and has south and west faces aggregating 300 feet in length and 17 feet in height.

The stone is typical cotton rock, having a blue color at the bottom and a gray or buff tint near the surface. The beds are from four to twenty inches in thickness.

The stone has been used in and about the State buildings at Jefferson City. At present the quarry is not being operated.

KOELTZTOWN.

THE SCHLIEF QUARRY.

This quarry, which is owned by Albert Schlief of Westphalia, is located in the S. E. ¼ of the S. E. ¼ of sec. 4, T. 41 N., R. 10 W., about three-fourths of a mile east of the village.

Three beds, having a thickness respectively of 4, 10 and 22 inches, have been worked at intervals for a distance of 500 feet. The stone is a pitted dolomite, very similar to that quarried at the Hoer quarry near Westphalia. Quarrying consists chiefly in removing the surface stone where there is practically no stripping.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of pitted dolomite from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.79
Porosity	9.99 per cent.
Ratio of Absorption	3.98
Weight per cubic foot	157.0 lbs.
Tensile strength	364 lbs. per sq. in.
Crushing strength	12,641 lbs. per sq. in. on bed.
	8,743 lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	11,676.5 lbs. per sq. in.

These tests indicate that the stone lost as a result of the freezing test an average of 964.5 pounds per square inch.

LUTESVILLE.

Two quarries, owned respectively by J. H. Turley and E. P. Briggs and Mrs. Hahn, are located near this place.

THE TURLEY & BRIGGS QUARRY.

This quarry is located near the north limits of the town just west of the St. Louis, Iron Mountain and Southern railroad. It is situated on the east side of a bluff and has a face sixty feet long and ten feet high. The following is a description of the beds from top to bottom:

3 ft.	Gray, fine grained, compact, limestone. Contains many dries which break the stone into small pieces.
11 in.	Similar stone. Broken into small pieces by short tight seams.
1 ft. 4 in.	Gray, fine grained, sub-crystalline limestone, containing small cavities one-fourth to one-half an inch in diameter. This bed can be split in the middle.

1 ft.	3 in.	Limestone similar in texture to that in the bed above. Contains small nodules and geodes of quartz and dries.
2 ft.	8 in.	Fine grained, gray, limestone. Contains yellowish stratification planes along which it splits easily.
1 ft.	2 in.	Gray limestone.

This quarry was opened in 1902 and employs about six men. A small kiln has been built to test the stone for the manufacture of quick lime. The stone is being shipped to Oran, Missouri, where it is being used in the foundation to a large mill.

THE HAHN QUARRY.

This quarry, which is owned by Mrs. Hahn and operated by Jesse Hahn, is located three-eighths of a mile west of Lutesville. It is situated near the bottom of a hill and has a face 150 feet long. The stone is similar to that in the Turley and Briggs quarry, being a fine grained, magnesian limestone. It occurs in unlimited quantities and is suitable for rough rubble masonry. It is used exclusively to supply the local market. The following is a description of the beds from top to bottom.

2 ft.		Stripping.
4 ft.		Yellowish gray limestone containing stratification planes. Poor quality of stone.
	6 in.	Layer of dark flint nodules.
5 ft.		Yellowish, arenaceous limestone, containing a bedding plane near the middle. Contains dries.
4 ft.	2 in.	Yellowish gray, fine grained, magnesian limestone of the pitted type, described as occurring in the Jefferson City quarries.
3 ft.	6 in.	Thick bed of buff, grayish, siliceous limestone. This bed will split along bluish stratification planes.

The major joints strike N. 65° W., N. 74° W., and N. 35° E. No machinery is used other than hand tools.

MONA.

THE SHUTT IMPROVEMENT CO.'S QUARRY.

This quarry is located just west of Mona and twenty-three miles northwest of St. Louis. It is situated on a bluff on the south side of the Missouri river. The work of stripping and quarrying has extended about 960 feet along the bluff which rises 180 feet above the level of the railroad. The floor of the quarry is 70 feet above the tracks and the face is 40 feet high. The following is a description of the beds from top to bottom:

1-5 ft.	Stripping.
12 ft.	Fine grained, fossiliferous light gray to drab limestone in beds from two to ten inches in thickness. The surface stone has a buff color due to iron oxide. It is badly broken with joints.
3 ft.	Very ferruginous argillaceous limestone. Is very soft and has a yellowish buff color.

4 ft. 6 in.	Fine grained, fossiliferous limestone. Upper portion is gray and the lower buff color. Flint nodules occur throughout the bed, which separates into a number of thin layers.
1 ft. 10 in.	Buff colored, calcareous shale.
15 ft. 6 in.	Thick beds of light gray, medium to coarsely crystalline, fossiliferous limestone. Stratification planes separate the stone into a number of beds. Flint nodules occur near the top.
5 ft. 6 in.	Medium grained, crystalline, light gray limestone. Near the west end this bed has a buff color.
5 ft. 10 in.	Finely crystalline limestone, having a slightly drab color. Separated from the bed above by one inch of shale. Contains a number of dark stratification planes.

The thickness of the beds is not constant throughout the quarry. In the west part the upper beds are very irregular and contain considerable flint.

An opening has been made west of the present quarry in which the stone is exposed to the bottom of the bluff. The following is a description of the beds:

20 ft.	Very argillaceous, medium grained blue limestone.
14 ft.	Argillaceous, buff colored limestone. Contains geodes of dolomite and nodules of limonite. Very poor stone.
20-25 ft.	Coarse grained, bluish limestone, much harder than the two beds above.

The stone in this quarry will disintegrate rapidly when exposed to the atmosphere and is not desirable as a railroad ballast.

A large crushing plant has been erected just west of the quarry. The company is installing an overhead tram to carry the stone from the quarry to the crusher. The plant is equipped with two Gates crushers Nos. 5 and 8, a 150-horse power engine, two 80-horse power boilers, an air compressor, a two-foot bucket elevator and revolving screen. Compressed air drills are used in the quarry. The following sizes of stone are being made: 3¾ inch, 3½ inch, 2½ inch, 1½ inch, and dust.

The entire product is being used for ballast by the St. Louis, Kansas City and Colorado railroad. The quarry has been in operation about eight months.

ROCK VIEW.

THE BIENERT QUARRY.

Mr. G. A. Bienert of Cape Girardeau operates a crushing plant at Rock View, about ten miles south of Cape Girardeau. The quarry is opened along the west face of a bluff, south of the Cotton Belt tracks, upon land owned by the railroad.

The quarry consists of two openings, one on either side of the crusher. The bluff rises 125 feet above the side track. The quarry has a vertical face of 60 feet and the beds dip into the hill about 10° E.

DOLOMITE (JEFFERSON CITY).
Engineering Building, Rolla, Mo. (Basement constructed out of pitted dolomite).

The stone is a brittle dolomitic limestone, compact to finely crystalline. In color, it varies from a light to a very dark gray. Two beds of quartzitic sandstone, having a thickness of two feet six inches and two feet, respectively, occur at the bottom and ten feet from the bottom of the quarry.

The stone is hauled to the crusher in carts. The entire output is broken in a No. 5 crusher and used as ballast on the "Cotton Belt" railroad. The company has a side track to the crusher.

ROLLA.

The heavy bedded dolomite of the Jefferson City formation furnishes building stone for local use at this place. A number of quarries have been opened southwest of Rolla, which are worked intermittently as there is demand for the stone. The massive character of the masonry constructed from this stone is shown in Plate XIV.

THE MURRAY QUARRY.

This quarry, which is owned by John Murray and operated by I. T. Petraglio, is located about one and one-half miles west of Rolla. It is situated just south of the road and has been opened 110 feet along the west face of the hill.

The quarry face consists of six feet of heavily bedded dolomite. The stone is finely crystalline in texture and has a strongly mottled color, due to the irregular pockets of white, sugary quartz, which are disseminated throughout the gray colored stone. These pockets occur with such frequency along bedding planes as to give the stone a slightly banded appearance. Where especially abundant, they assist in capping the stone.

The ledge splits along a natural bed through the middle of the quarry face. Large blocks varying from three to six feet in length by eight to fourteen inches in thickness are quarried. The stone works well into heavy masonry and is very durable. After long exposure the sugary quartz in the cavities at the surface weathers out, leaving the stone with a rough hackly surface. This can be seen both in the natural outcrop and in walls which have been laid for some time. One hand derrick is used in getting out the stone.

THE LIVESAY, MALCOLM AND WHITE QUARRIES.

John Livesay owns a quarry which joins the Murray quarry on the south, and in which the same ledge of stone is worked. The Malcolm quarry is located along the west face of a hill just north of the St. Louis and San Francisco railroad south of the Murray quarry. The quarry is

covered with rather heavy stripping which has resulted in its practical abandonment.

Mr. P. White owns a quarry located south of the Malcolm quarry. It is on the south side of the hill, south of the railroad, and has been operated quite extensively in the past.

In general, the stone from these quarries is the same, being pitted dolomite similar to that obtained at the Murray quarry. Large blocks can be quarried. The quarries are only operated when there is demand for the stone. It was used in the basement of the new Engineering building of the School of Mines at Rolla.

When first cut and dressed it has a light gray mottled color which gradually becomes darker upon exposure to the atmosphere.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of pitted dolomite from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.801
Porosity	13.00 per cent.
Ratio of Absorption	5.341
Weight per cubic foot	152.2 lbs.
Transverse strength	851.3 lbs. per sq. in.
Tensile strength	220.0 lbs. per sq. in.
Crushing strength	8486.7 lbs. per sq. in. on bed. 9161.0 lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	9323.3 lbs. per sq. in.

Although the porosity of this stone is 13 per cent. the results of these tests seem to indicate that the stone is injured very little by alternate freezing and thawing. The high porosity in this stone is due to the small hackly cavities which it contains. Outside of these, the stone is dense and compact. This is a very clear illustration of how the porosity of a stone may not be an indication of its durability.

UNION.

THE ST. LOUIS, KANSAS CITY & COLORADO RAILROAD CO.'S QUARRY.

This quarry is located about one mile east of Union and is connected by spur with the main track. It has a face 110 feet long and six feet six inches in height. The stripping consists of from one to three feet of clay and stone.

The stone is typical Jefferson City dolomite. The upper three feet is a solid bed which can be split into pieces of any desired thickness. The lower part of the quarry is separated by bedding planes into layers from four inches to one foot in thickness.

Occasional joints strike N. 60° E. and N. 60° W. They are not frequent enough to materially affect quarrying operations. Some of the stone contains short dries on account of which it breaks into irregular pieces.

The entire output of this quarry is being used for the construction of culverts.

WESTPHALIA.

THE HOER QUARRY.

The surface rock over a greater portion of Osage county is Jefferson City (Second Magnesian) limestone. This formation consists of the so-called cotton rock and pitted dolomite, the latter of which occurs in thick beds throughout the county. Quarries have been opened in many places, the stone being used to supply local demands.

One quarry is operated at Westphalia which has a face 75 feet long and 12 feet high. It was opened in 1885, is owned by Mr. C. Hoer and operated by Joseph Weibel.

It consists of from four to six feet of clay stripping and twelve feet of stone, the upper seven feet of which splits into beds from two to sixteen inches in thickness. The lower five feet does not occur in beds, but can be easily capped into layers of from two to four inches. The sixteen-inch bed at the base of the upper ledge is the most desirable stone.

All of the stone is very much the same, being a semi-crystalline, dark gray, magnesian limestone, containing small irregular cavities filled with a white, sugary quartz, which weathers out upon exposure, leaving a very rough, hackly surface.

The principal joints strike N. 60° E., N. and S. and N. 60° W. The beds dip gently to the east and west from the middle of the quarry.

The five-foot ledge splits very easily and is suitable for making blocks 10, 12, 14 and 16 inches in thickness. This stone is suitable for culverts, bridge abutments and other constructional purposes, in which rough stone can be used. It is very similar to that used in the foundation to the new School of Mines building at Rolla. The output is used locally.

PART II. SANDSTONE.

COLE CAMP.

Two sandstone quarries, located about one-half mile south of this place, are operated respectively by Neff Bros. and John Chmelir. The stone is used chiefly for flagging, curbing and foundations in the immediate vicinity of Cole Camp.

THE NEFF QUARRY.

This quarry, which is located in sec. 35, T. 40 N., R. 21 W., is owned by R. M. Neff and operated by R. M. and Charles Neff. It has been worked intermittently during the summer months since 1884.

The face of the quarry is about 400 feet long and about 14½ feet high. Underneath a stripping of two feet of clay occur the following beds:

4 ft.	Grayish, buff colored sandstone. Can be split into layers of almost any desired thickness. Contains a number of dry seams.
1 ft. 6. in.	Decomposed stone.
8 ft.	Medium grained, white sandstone, containing some iron in the upper part. Can be split into layers four inches or more in thickness. The stone is rather soft when first quarried, but hardens upon seasoning.

In the middle of the quarry the stone in the lower bed has been indurated until it is almost a quartzite. This is not quarried, owing to the difficulty experienced in cutting and dressing it. Near the outcrop, the stone splits into layers two inches in thickness. As the quarry is worked into the hill, the beds become thicker. Some of the bedding planes show ripple marks.

This stone is used for caps, sills, foundations, ashler blocks, etc.

THE CHMELIR QUARRY.

This quarry, which is one-fourth of a mile southeast of town, is owned and operated by John Chmelir. It consists of three openings, only one of which is operated at the present time. This opening consists of two beds of gray sandstone, outcropping in a creek bed. North of this is another opening, which has been worked extensively. It has a face 65 feet long, consisting of six feet of red sandstone in beds from two to eighteen inches in thickness.

This sandstone is quite soft and friable and contains considerable iron oxide. The middle of the ledge shows cross-bedding and ripple marks are very abundant. The principal joints strike N. 40° E, and N. 65° W. The rock contains occasional dry seams. The stone is covered with from two to four feet of soil and toward the west end of the quarry the beds dip slightly to the southwest. The stone apparently improves as it is worked into the hill.

UNION.

Two quarries are operated near this city, the Kasmann quarry from which sandstone is obtained for local consumption and the St. Louis, Kansas City and Colorado railroad quarry which produces limestone used in the construction of culverts.

THE KASMANN QUARRY.

This quarry is located one mile north of Union in sec. 21, T. 43, R. 1 W. It is owned by C. Deptner and operated by Henry Kasmann. It consists of a number of different openings in the valley and along the hillside, from all of which a very white sandstone is obtained.

The opening which is now being operated has a face sixty feet long and ten feet high. The stripping consists of three feet of soil and flint. The stone consists of two beds of fine grained white limestone, which splits readily with plug and feathers. It is used for flagging, curbing, foundations, caps, sills, steps, etc.

This stone has a very uniform texture and is excellent for most building purposes. Buildings in which it was used fifteen years ago show little sign of wear.

MISCELLANEOUS.

The sandstone belonging to the Cambro-Ordovician is quarried in many places in the Ozark plateau region and is used for a variety of purposes, including buildings, sidewalks and culverts. In many localities it is hard and firm and occurs in thin beds which when quarried make excellent flagging for sidewalks. Although this stone when used in sidewalks may wear faster than cement concrete or brick, nevertheless it is more desirable for residence streets in the smaller cities and towns of the State.

At Pacific, Crystal City, Klondike, Gray's Summit and other places the Pacific (St. Peters) sandstone is quarried in large quantities and sold to glass manufactories, foundries, and other consumers of high grade sand. It is exceptionally pure silica and is unexecelled for the manufacture of plate glass. It occurs in almost limitless quantities.

CHAPTER VII.

SILURIAN AND KNOWN ORDOVICIAN.

The rocks which are positively known to belong to these systems occur chiefly in the eastern part of the State, near the Mississippi river. The formations are chiefly limestone, in which occur several thin horizons of sandstone and shale. The active quarries are situated chiefly in the limestone and are located at Cape Girardeau, Bowling Green, Elsberry, Graysboro and Jackson. The following descriptions of the individual quarries give an excellent idea of the character of the stone in the different localities.

BOWLING GREEN.

Several quarries have been opened in the Niagara limestone east of this city, but the only one which is now operated is owned by P. L. Calwell and leased by J. F. Butters and Son.

THE BUTTERS & SON QUARRY.

This quarry is located two miles east of the city and consists of two openings, one on each side of the Chicago and Alton railroad. The one south of the railroad was opened about thirty-five years ago, but has not been operated for ten or fifteen years. The one north of the tracks was opened about two years ago and is the only one now being operated.

It has a face about 60 feet long and 32 feet high. The stone occurs in thick massive beds as shown by the following section from the top to the bottom:

2 ft.	Clay stripping.
4 ft.	Consists of three beds of hard, buff colored limestone. Waste.
15 ft.	Fine grained, mottled limestone. This stone has large, irregular, yellowish spots and the upper part contains many small cavities. The lower five feet is separated from the upper portion by a suture joint. The stone below this joint is fine grained, white limestone, showing no iron oxide and very few cavities.
12 ft.	Bluish gray mottled limestone, containing occasional cavities. The mottling is due to weathering, chiefly along the stratification planes. The stone contains dark spots parallel to the bedding. Small crystals of pyrite occur throughout this bed.

The major joints are from 15 to 25 feet apart, permitting the quarrying of stone of any convenient size. The major joints strike N. 80° W.;

the minor joints N. 55° E. The stone for a distance of six to eight inches, on either side of the joints, has a buff color.

The upper ten feet contains one bedding plane about two feet from the top. The stone has a somewhat mottled blue and gray color when freshly quarried. After exposure to the atmosphere, the dark spots, which are probably caused by ferrous iron, change to brown through oxidation. The iron is most abundant near the top of the ledge. The stone contains many small cavities, from one-eighth to one inch in diameter, especially in the upper half of the ledge. These and the mottled color prevent the use of it for anything but rough constructional work. The stone is suitable for bridge abutments and other purposes for which large blocks are required and a uniform color is not essential.

The lower five feet of the upper ledge is a finely crystalline, magnesian limestone, having a very uniform light gray color. It contains very little iron and the few small cavities which are present are not sufficiently abundant to injure its appearance. This bed can be split along the stratification planes into blocks of almost any thickness. Upon exposure, the color changes to a light brownish yellow, not as dark as that of the beds above and below. This stone is the best in the quarry and may be used for ashler blocks, caps, sills and other parts of buildings.

The twelve-foot ledge is a solid bed of magnesian limestone. It has a roughly banded buff and grayish blue color. The streaks of buff show along the stratification planes of the stone which has been exposed to the weather. In the lower part of the bed, the buff colored streaks do not occur, the stone exhibiting simply light and dark blue streaks. Occasional cavities, somewhat larger than those in the fifteen-foot ledge, occur in this bed. Some of the cavities contain calcite. This stone is stronger and more compact than that in the fifteen-foot ledge and is somewhat more difficult to cut and dress. For this reason it has not been quarried very extensively. It is suitable for most purposes for which dimensional stone is required.

All the stone breaks with a smooth, even fracture and can be worked to advantage with plugs and feathers. At the time the quarry was examined, the stone from the upper ledge was being broken into one-foot cubical blocks, to be used in short columns. These blocks are broken so smoothly with plugs and feathers that very little dressing is required.

The opening on the south side of the Chicago and Alton railroad contains stone which, in general, is very similar to that in the opening just described. The chief difference is in the greater abundance of bedding planes and the presence of several inclined joints. The following section shows the character of the beds from the top to the bottom.

2 ft.	Broken stone stripping.
12 ft.	Fine grained, buff colored magnesian limestone. Contains numerous cavities.
10 ft.	Fine grained, dark gray limestone. Contains cavities varying in size from one-fourth to one inch in diameter. This ledge contains bedding planes which split the stone into layers from two to six inches in thickness.
14 ft.	Blue limestone, containing dark and light spots, which give it a mottled appearance. Contains many calcite geodes and occasional flat lenses of chert. The principal bedding plane occurs two feet from the bottom.

The major joints strike N. 80° W. The minor joints strike N. 40° E. and N. 20° E. One of the major joints is filled with a thin layer of iron oxide probably an alteration product of iron sulphide. On both sides of the joints, the stone has been weathered to a buff color. The inclined joints mentioned above, although not numerous, occasion considerable waste.

Although this quarry is situated not over 200 yards from the tracks of the Chicago and Alton railroad, it is not provided with a spur or side track. Any stone which is shipped must be hauled two and a half miles to the depot. This greatly handicaps the development of the quarry.

The abutments of the Chicago and Alton railroad bridge, near the quarries, were constructed out of this stone. After twenty-five years' exposure to the atmosphere, these abutments show no sign of wear. The edges and corners of the blocks are clean cut and sharp and the faces still retain clear and distinct the chisel marks.

LABORATORY EXAMINATION.

Chemical Tests.—The following is a chemical analysis of the white limestone from this quarry:

Insoluble	13.99
Fe_2O_3, Al_2O_3	1.62
$CaCO_3$	49.77
$MgCO_3$	34.46
Total	99.84

Physical Tests.—Two-inch cubes from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.76
Porosity	10.62 per cent.
Ratio of Absorption	4.365
Weight per cubic foot	154.3 pounds.
Transverse strength	2023.32 lbs. per sq. in.
Tensile strength	598. lbs. per sq. in.
Crushing strength	8,881.6 lbs. per sq. in. on bed. 6,019. lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	11074. lbs. per sq. in.

In the freezing test of the second set of samples in which the crushing strength of the fresh stone was 6,019 pounds per square inch, the specimens cracked parallel to the bedding planes and their crushing strength could not be determined. In the first set the crushing strength of the frozen samples was 2,192.4 pounds per square inch higher than that of the fresh samples.

CAPE GIRARDEAU.

The Silurian and Ordovician strata which comprise the geological formations of this county contain excellent stone for building and other constructional purposes. Shumard*, in his report on Cape Girardeau county, describes the occurrence of these strata. Mr. E. O. Ulrich of the United States Geological Survey, who is at present making extensive correlations of the Paleozoic strata throughout the central portions of the United States, has devoted considerable time to the geological succession in this State, along the Mississippi river from St. Louis south. As a result of this work Mr. Ulrich proposes using the following old and new names for the strata which occur over extensive areas in Cape Girardeau, Perry, Jefferson and St. Louis counties, and of which he will soon publish full descriptions in a paper on the Paleozoic Section in the Mississippi Valley.**

(1) The Birdsville formation embracing the shales and sandstones and thin limestones forming the upper part of the Chester group. Name derived from Birdsville, Livingston county, Kentucky.

(2) The Tribune limestone which is proposed for the main limestone of the Chester group above the Cypress sandstone. It occupies the interval between the Birdsville above and the Cypress sandstone (=Aux Vases sandstone) beneath. The typical locality is in Crittenden county, Kentucky.

(3) The name Cypress sandstone having been proposed by Englemann in 1868 as a geographic designation for Swallow's "Ferruginous sandstone," is adopted in preference to the latter name Aux Vases sandstone proposed by Keyes.

(4) The Ste. Genevieve limestone is adopted from Shumard who distinguished the formation in 1860, and described it more fully in 1873. This formation proves to be more closely related to the Chester group than to the underlying St. Louis limestone.

(5) The St. Louis limestone is restricted to the typical fine grained

**Information sent the author in a letter January 9, 1904.

*Geol. Surv. of Missouri, 1855 to 1871, p. 260.

and often cherty limestone formation to which the name was originally applied.

(6) The name Spergen Hill limestone is adopted for the oölitic and granular limestone division of the group shown beneath the St. Louis limestone at the Meramec Highlands quarry and in the equivalent beds in the quarry at Wicks station. The Bedford stone of Indiana is derived from this formation.

(7) The Warsaw limestones (and shales) occur at the base of the group at Meramec Highlands and extend northward from that point. This, together with the overlying Spergen Hill and St. Louis limestones are embraced in a group for which I propose the name Meramec group.

(8) The Tullahoma formation (Safford) embraces the southern equivalents of the Osage and Kinderhook groups and may be recognized as far north as Ste. Genevieve, Missouri. North of this locality and the axis that here separated the basin at this time the two groups are readily distinguishable.

(9) In the area about Glen Park and Sulphur Springs I have further distinguished, at the base of the Kinderhook and perhaps top of the Devonian, the Sulphur Springs formation. This formation is divisible into three members, a thin sandstone (about 10 feet) at the top to which the name Bushberg sandstone may be applied; beneath this a 1 to 5-foot bed of oölitic limestone, probably early Kinderhook in age, which may be called Glen Park (oölitic) limestone; and, finally, at the base a shale, 0-15 feet thick, either earliest Kinderhook or late Devonian in age, for which no subordinate designation is proposed.

The formations from the Tullahoma to the Birdsville, both inclusive, are fully described in Mr. Ulrich's report on the stratigraphic geology of the lead, zinc, and flourspar deposits of Western Kentucky (in press).

(10) The Grand Tower limestone (Keyes, emend) contains the local representatives of the Hamilton and Onondaga limestones of the east.

(11) The Clear Creek limestone or chert (Worthen) is the name to be applied to the extremely cherty limestone south of Wittenberg.

(12) The Bailey limestone, from Shumard's old locality, Bailey's Landing, is proposed for the argillaceous limestones and shales containing the New Scotland Helderbergian faunas at Red Rock landing and above. This is practically equivalent to Safford's Linden limestone of Tennessee.

(13) The Bainbridge limestone embraces all the Silurian limestones beneath the preceding in the river bluffs for some miles above and below

Bainbridge, Missouri. It also occurs above and below Thebes, Illinois; nearly equivalent to Safford's Clifton limestone of Tennessee.

(14) The name Girardeau limestone is adopted in this amended form for the limestone described by Shumard in 1873, as the Cape Girardeau limestone.

(15) The Thebes formation embraces three subdivisions, viz.: a sandstone in the middle with a shale above and beneath. This is an extension of the term as used by Worthen.

(16) The Kimmswick limestone is a new name referring to the more or less crystalline limestone being quarried at Graysboro, Cape Girardeau, Glen Park, Kimmswick and other localities in southeastern Missouri. The thin bed generally found at the top, 2 to 5 feet, holding the Fernville Richmond fauna, is not included.

(17) The Plattin limestone is a new name proposed for the fine grained limestone formation between the Kimmswick and the "First Magnesian" and which has generally been called either Trenton or lower Trenton. It is the local but only partial equivalent for the rocks of the Stones River group in central Kentucky and Tennessee. The formation takes its name from Plattin Creek, Jefferson county, near the mouth of which it is well exposed.

(18) The name Joachim limestone, proposed by Winslow, is adopted for the "First Magnesian."

In the vicinity of the city of Cape Girardeau three of these formations have been quarried. Just north of the city the Thebes sandstone, which caps the hills, was in former years quarried quite extensively. Near the northwest limits of the city the Kimmswick limestone has been quarried extensively for building stone and the manufacture of quicklime. At this locality the stone takes on much more the character of marble than at Kimmswick or Glen Park and is known locally as the "Cape Girardeau marble." It makes an excellent quicklime and is a durable and handsome building stone.

South of the city quarries have been opened in the Plattin or Lower Trenton limestone, the stone being used for railroad ballast and buildings. Two quarries have been opened in the Bainbridge limestone, the stone being used chiefly for rip rap along the Mississippi river.

The quarries in the vicinity of Cape Girardeau are operated by Burke Bros., Edward Hely, W. L. Killebrew, Edward F. Regenhardt, J. C. Seiler, Wm. Regenhardt and the Cape Lime and Marble Co. The last named company is manufacturing quick lime from the Kimmswick limestone. This quarry will be described in a subsequent report on "Quick Lime and Cement."

THE BURKE BROS. QUARRY.

This quarry is located about ten miles north of Cape Girardeau, near the St. Louis and San Francisco railroad. It is situated on the northeast side of one of the river bluffs and has a face about 350 feet long and 60 feet high. The stone is a bluish gray, finely crystalline limestone, occurring in beds from six inches to two feet in thickness. Considerable flint occurs in nodules and layers throughout the quarry. Steam drills and derricks are used in getting out the stone, which is used chiefly for rip rap.

THE HELY QUARRY.

This quarry is located about two miles south of Cape Girardeau. The stone is used chiefly for crushing. The face of the quarry is about 600 feet in length and approximately 45 feet in height. There is practically no stripping. The following is a description of the beds from the top to the bottom:

15 ft.	Dark colored, finely crystalline limestone, occurring in beds from six inches to two feet in thickness.
3 ft.	Yellowish gray, fine grained limestone, containing small crystals of calcite. Separates into thin layers.
11 ft.	Dark gray, compact limestone, containing small crystals of calcite. The stone breaks with an irregular splintery fracture.
14 ft.	Drab to black, compact limestone. Splits into layers from two to twelve inches in thickness. Is very brittle and breaks with a conchoidal, splintery fracture.

The quarry is equipped with a crushing plant, having a capacity of 1,000 cubic yards per day. It consists of No. 4 and No. 8 Gates crushers with the usual accessories. Power is furnished by an engine and two 100-horse power boilers. Steam drills are used and the stone is hauled to the crusher in steel cars, along the tracks which radiate to all parts of the quarry. A side track connects the plant with the St. Louis, Iron Mountain and Southern railroad.

This is one of the most complete and best equipped crushing plants in Missouri. From April 1st to December 31st, 1903, 50,000 cubic yards of crushed stone was produced.

THE KILLEBREW QUARRIES.

Mr. W. L. Killebrew owns and operates two quarries, one of which is located just south of the Hely quarry, and the other along the river bluffs, about nine and a half miles north of the city.

The first quarry is situated on a hillside and has a face about 400 feet long and 40 feet high. The stone is a very fine grained, bluish black limestone, in beds from six inches to two feet in thickness. It splits readily along the bedding planes, which dip about 4° to the northwest.

Edward Hely Crushing plant, Cape Girardeau, Mo.

Mill at the Edward Regenhardt quarry, Cape Girardeau, Mo.

The stone breaks with a splintery fracture and is very good for railroad ballast and macadam. The heavier beds might be used for building.

The major joints strike N. 35-40° W. The minor joints strike N. 20° E.

All of the stone is crushed for ballast, being separated into two sizes 1½ inch and screenings. At present this quarry is not in operation.

The second quarry, which is located near Bainbridge landing, is situated along the east side of the river bluffs. It consists of two openings having a face aggregating 600 feet in length and 45 feet in height. A small ravine breaks the continuity of the quarry face, on account of which it is worked as two openings.

The stone is a finely crystalline, bluish gray limestone. Flint nodules occur throughout the quarry. The beds are from six inches to two feet in thickness. Steam drills are used in the quarry and the stone is hauled in dump carts to the river where it is loaded on barges. It is used exclusively for rip rap along the Mississippi river.

THE EDWARD F. REGENHARDT QUARRIES.

Mr. Regenhardt operates two quarries, one, the "Normal" quarry, is located just east of the fair grounds, near the west limits of the city; and the other is located two miles south of the city, just beyond the Killebrew quarry.

The Normal quarry consists of a single irregular opening, 70 feet east and west and 100 feet north and south, having a maximum vertical face of 35 feet. This quarry was opened in 1901 to obtain the stone to be used in the Normal school building at Cape Girardeau.

This stone is a coarsely crystalline, heavily bedded limestone, having much the appearance of marble. It is almost pure white in the bottom of the quarry, but has a faint pinkish or bluish gray tint near the surface. Fine suture joints occur from two inches to three feet apart. The stone contains small cavities, known locally as "sand holes." These are not sufficiently abundant to cause any considerable waste.

The quarry is covered with a very light stripping of clay. Large irregular cavities and open joints, resulting from weathering, occur throughout the quarry. These are usually filled with red clay, which occasionally extends to the bottom of the quarry. These cavities and open joints make it difficult to obtain large blocks, free from the effects of weathering. It is the practice to quarry irregular blocks by hand and saw them in the mill. The stone in the upper part of the quarry is said to be harder than that deeper down. It can be sawed at an average rate of two inches per hour. The stone works nicely under the hammer, and

has a pleasing appearance when used as in the Normal school buildings at Cape Girardeau. An excellent grade of white lime is manufactured out of this stone.

This quarry is equipped with a Wordwell channeling machine, a crushing plant and two gang-saws.

The second quarry operated by Mr. Regenhardt is located about two miles south of the city on a bluff just south of the Killebrew crusher, on land leased from St. Vincent's College. It has a face 70 feet long and about 15 feet high. The following are the thicknesses of each of the beds from top to bottom: 4 ft., 1 ft. 5 in., 1 ft. 8 in., 1 ft. 9 in., 1 ft., 1 ft. 10 in., 1 ft. 2 in., 2 ft. 4 in., 1 ft. 2 in., 1 ft. 8 in. Some of the stratification planes have a black color. Near the crossing of these planes and the joints the stone weathers more rapidly than in other parts of the quarry.

All the stone in this quarry has the same general texture and color. It is a very fine grained, compact limestone, having a brownish black to very dark blue color. It is very hard and breaks with a sub-conchoidal fracture.

The major joints strike N 40°-50° W. A minor set strikes N. 55° E. These parting planes are taken advantage of in quarrying and are sufficiently far apart to permit the removal of blocks of practically any required dimensions.

The stone has been used in the basement of the new Normal school buildings and in other structures in Cape Girardeau. The dark color of the stone is in striking contrast with the nearly white "Cape marble."

THE WM. REGENHARDT QUARRY.

This quarry is located near the north limits of the city and is situated on one of the Mississippi river bluffs. The stone, which is known as the Thebes or Cape Girardeau sandstone, caps the hills along the river. The first stone used in Cape Girardeau was obtained from this formation.

It is a yellow, fine grained sandstone which is soft when first quarried but hardens upon exposure. The formation is about fifteen feet thick and consists of beds from three feet to six feet in thickness. When used above the ground, it appears to be very durable, as shown by a dwelling house built out of it in 1853. For half a century, this building has been exposed to the weather without showing any very marked evidence of deterioration. At one time, this stone was shipped quite extensively through the extreme southeastern part of Missouri along the Mississippi river. At present very little is being quarried.

The face of the quarry is about 600 feet long and 15 feet high. It is covered with a stripping of twenty feet of loess, on account of which, it is said to have been abandoned.

TRENTON LIMESTONE (CAPE MARBLE).
State Normal School, Cape Girardeau, Mo.

THE J. C. SEILER QUARRY.

This quarry is located southwest of the Regenhardt quarry and consists of a face 50 feet long, in which two principal ledges, 26 and 36 inches in thickness, are worked. The stone is essentially the same as that in the Regenhardt quarry. The output is used to supply the local market.

ELSBERRY.

THE CRYSTAL CARBONATE LIME CO.'S QUARRY.

This quarry is located on the west side of the Burlington track, about a half a mile south of the depot. It is leased by C. C. Pratt and G. M. Cash under the firm name of "The Crystal Carbonate Lime Co." The lease is for twenty years and includes a frontage of 4,000 feet, owned by Mrs. Wigginton.

The face of the quarry, at the time it was inspected, consisted of the following succession of beds from top to bottom:

15-40 ft.	Loess—Clay—Stripping.
20 ft.	Beds of limestone varying in thickness from six inches to two feet. These layers are discolored with clay and iron oxide which has washed into the seams from above.
3 ft.	Limestone. Can be capped into beds from one to two feet in thickness.
3 ft. 6 in.	Very solid bed of limestone, containing many fossils.
4 ft. 3 in.	Thick bed of limestone. Very many fossils, especially near the top.
3 ft. 7 in.	Coarsely crystalline bed of limestone. Occasional small cavities lined or filled with calcite crystals. Many fossils.
5 ft. 2 in.	Coarsely crystalline limestone containing numerous fossils, mainly brachiopods. Most abundant near the middle of the bed.
3 ft. 4 in.	Coarsely crystalline, grayish white limestone; somewhat fossiliferous.

There is no evidence of pyrite in the rock which is being quarried. The discoloration of the upper beds is due to the washing of clay and iron oxide into the seams and along the beds from the loess which covers the surface.

The bedding planes are very uneven below the middle of the face. Above this horizon they are comparatively smooth. The jointing is nearly vertical, breaking the beds into blocks of various dimensions. The largest blocks would probably measure 10x15 feet. There are two prominent sets of joints striking nearly N. 65° W. and N. 25° E.

The south end of the quarry shows very tight, close, north and south joints which break the rock into small shaly fragments. The east and west joints are the most regular, and instead of having an east face, the quarry should have a north face. This change in the direction of working the quarry will be made as soon as practicable.

The company is equipped with modern machinery, including steam drills, crusher, pulverizers, screens, elevators, etc.

At the present time the product is being crushed or pulverized for use in smelting furnaces, glass works, concrete, ballast and similar purposes.

The quarrying has been carried on with little regard to the jointing planes, and no attempt has been made to secure dimensional stone. Dynamite and sledges are used in breaking up the blocks. Undoubtedly the stone from the thicker beds, if properly quarried and selected, could be used for many constructional purposes. Channeling machines could be used on some of the ledges, and in this way much more building stone could be procured than by blasting.

The main objections to this stone for buildings are the fossil layers, the drusy cavities and the loose texture of some of the stone.

The stone is well adapted to the manufacture of quick lime and could probably be used successfully in the manufacture of Portland cement. This is true if the stone contains 99 per cent. calcium carbonate, as reported by the operators.

GRAYSBORO.

Two quarries are located near the Mississippi river at this place, both of which are operated to supply crushed stone used in the erection of the Thebes bridge, at Thebes, Illinois. The land on which the quarries are located is owned by Mr. Gray, to whom a royalty of 5 cents per cubic yard is paid.

The stone is obtained from the Trenton-Kimmswick formation. It is a very coarsely crystalline, light gray limestone, similar to that at Ste. Genevieve. It is fossiliferous, contains an occasional fine suture joint and occurs in thick beds. It is very pure and makes an excellent grade of quicklime.

The two quarries referred to above are operated respectively by C. McDonald & Co., and The Patterson Construction Co.

THE McDONALD CO'S QUARRY.

This quarry, which was opened in January, 1903, will probably be operated only until the completion of the Thebes bridge. It is equipped with a crushing plant, consisting of No. 3 and No. 6 Austin crushers with screens and other necessary accessories, a derrick and other quarrying appliances.

The face of the quarry is 150 feet long and 25 feet high. The upper sixteen feet splits into thick beds along well defined bedding planes. The stone in the lower part of the quarry is massive. Irregular cavities and

large clay seams occur throughout the quarry, chiefly in the upper twelve feet. A mud seam, eight feet in width, extending to the floor was noted near the west end of the quarry.

Thirty men are employed and the plant has a capacity of from 600 to 700 cubic yards of crushed stone per day.

THE PATTERSON CONSTRUCTION CO.'S QUARRY.

This quarry joins the McDonald quarry on the west and the stone is, in all respects, similar. Clay seams are abundant, increasing considerably the expense of getting out the stone.

The quarry is equipped with a crushing plant, consisting of a No. 6 crusher and accessories. The stone is loaded on barges and transported to Thebes where it is used for concrete work in the Thebes bridge.

JACKSON.

Several small quarries have been opened in the vicinity of this city to supply the local demand for building stone. The stone occurs in well stratified beds of moderate thickness. It is fine grained, compact, fossiliferous and brittle, and has a dark blue to black color. Weathering changes the color to a buff.

Quarries have been opened in this vicinity by the following persons: John Kesterson, G. F. Green and T. McFarland, Edward Hendricks, Levi Hurst and W. H. Amnette.

THE GREEN & McFARLAND QUARRY.

This quarry is located a half a mile north of the city and is situated in the bed of the west fork of Hubble creek, along which the stone outcrops for about four miles.

Four ledges of stone, 9 in., 8 in., 12 in., and 11 in. in thickness, are worked at this quarry. The stone is a solid dark blue to black fossiliferous, fine grained limestone which breaks with a splintery fracture. It is covered with three feet of gravel and soil stripping.

The major joints strike N. 32° W. and N. 50° E. and are from six to fifteen feet apart. These joints assist very greatly in quarrying the stone, which is used chiefly for caps, sills, steps and foundations. A derrick and steam drill have been used at this quarry.

Two abandoned quarries are located along this creek between the Green & McFarland quarry and the city. They are owned respectively by Wm. Bird and Mrs. Ed. Hendricks, both of Cape Girardeau. The stone is similar to that in the Green & McFarland quarry.

THE HURST AND AMNETTE QUARRIES.

Two small quarries owned and operated respectively by Levi S. Hurst and W. H. Amnette are located on the east branch of Hubble creek. The stone in each of these quarries is a fine grained, bluish, fossiliferous limestone. It is rather shelly and not suitable for heavy constructional work. It is difficult to quarry and breaks with a rough surface.

Quarrying has not extended beyond the zone of weathering. Probably as the quarries are worked deeper, the quality of the stone will improve.

THE KESTERSON QUARRY.

This quarry is located in sec. 7, T. 31, R. 13 E., one mile east of Jackson. It was opened about ten years ago by Richard Niblet, and during the past two years has been operated by John Kesterson. It is at the bottom of a steep hill and has a face 150 feet long and 30 feet high. The stripping is very light, not exceeding two feet.

The stone occurs in beds varying in thickness from two inches to two feet. It is a dark blue, fine grained, fossiliferous limestone, containing small geodes of calcite. A number of the beds contain thin shaly seams, along which the stone splits easily. Toward the bottom of the quarry, the stone has a somewhat darker color. It is not affected by frost and can be quarried at all seasons of the year.

The major joints strike N. 45° E., N. 15-20° E. and N. 25° W. Many of them are open and filled with clay. Dries are not very abundant. The major joints assist very greatly in quarrying the stone. It weathers to a yellowish brown color along the jointing planes.

The stone is used for sidewalks, curbing, sills, steps and foundations. It may be seen in the Cape County Savings Bank, in H. H. Muellers' store and many other buildings in and about Jackson. It has also been shipped to Saxton, Oran and Charleston, Missouri.

LABORATORY EXAMINATION.

Chemical Tests.—The following is a chemical analysis of the limestone from this quarry:

Insoluble	4.66
Fe_2O_3, Al_2O_3	.28
CaO	52.20
MgO	.07
CO_2	41.72
Total	99.92

Physical Tests.—Two-inch cubes of this stone were tested in the laboratory with the following results:

Specific Gravity	2.705
Porosity	.32 per cent.
Ratio of Absorption	0.12
Weight per cubic foot	168.5 lbs.
Transverse Strength	3311.6 lbs. per sq. in.
Tensile Strength	1079.5 lbs. per sq. in.
Crushing strength	27,183. lbs. per sq. in. on bed. 21,356. lbs. per sq. in. on edge.
Crushing strength of specimens subjected to freezing test	26,117.5

The tests show that the frozen samples of this stone tested on an average of 1,065.5 pounds per square inch less than the fresh sample.

KISSINGER.

A hurried examination was made of the quarry at Forgiss Bluff, located about half a mile north of Kissinger. This bluff extends for about one-fourth of a mile along the west side of the Burlington tracks. The lowest stratum examined was about forty feet above the level of the railroad. The following beds were noted, beginning at the top of the vertical exposure and extending downward:

20 ft.	Rough, hackly limestone, containing shaly layers.
6 ft.	Limestone. Solid ledge of good stone.
3 ft.	Similar to the bed immediately above.
3 ft.	Limestone which can be capped into two or three layers. Buff colored and has a sandy appearance.
15 ft.	A poor grade of limestone having a heterogeneous texture.
8 ft.	Thick beds of buff colored limestone. Can be capped into two four-foot beds. Contains small particles of iron oxide and a few calcite geodes.

The major joints in this quarry are vertical or nearly so, and strike N. 55° W. and N. 55° E. They are far enough apart to permit the quarrying of large dimension stone. The quarry face is parallel to the N. 55° W. joints.

The six and eight-foot beds consist of very solid stone, having a uniform texture and color. The eight-foot bed will work easily and dress nicely. The small particles of iron oxide are not large enough to cause discoloration.

These two ledges contain stone which is somewhat softer than that occurring at other horizons in this vicinity, but it can be easily cut and carved, reducing very greatly the usual cost of preparing the stone for use.

The nature of the stone is such, however, that it should be worked without powder or dynamite. Either of these will shatter it to such an extent as to make it unsuitable for heavy constructional work.

CHAPTER VIII.

MISSISSIPPIAN (SUB-CARBONIFEROUS).

This system, which consists chiefly of limestone, has a wide distribution in the southwestern, west central and northeastern parts of the State. The stone is chiefly a white or grayish colored, coarsely crystalline limestone. It is in this formation that the Carthage quarries are located. The following are detailed descriptions of the principal quarries located in this formation.

BLACKWATER.

THE COLYER BROS. QUARRY.

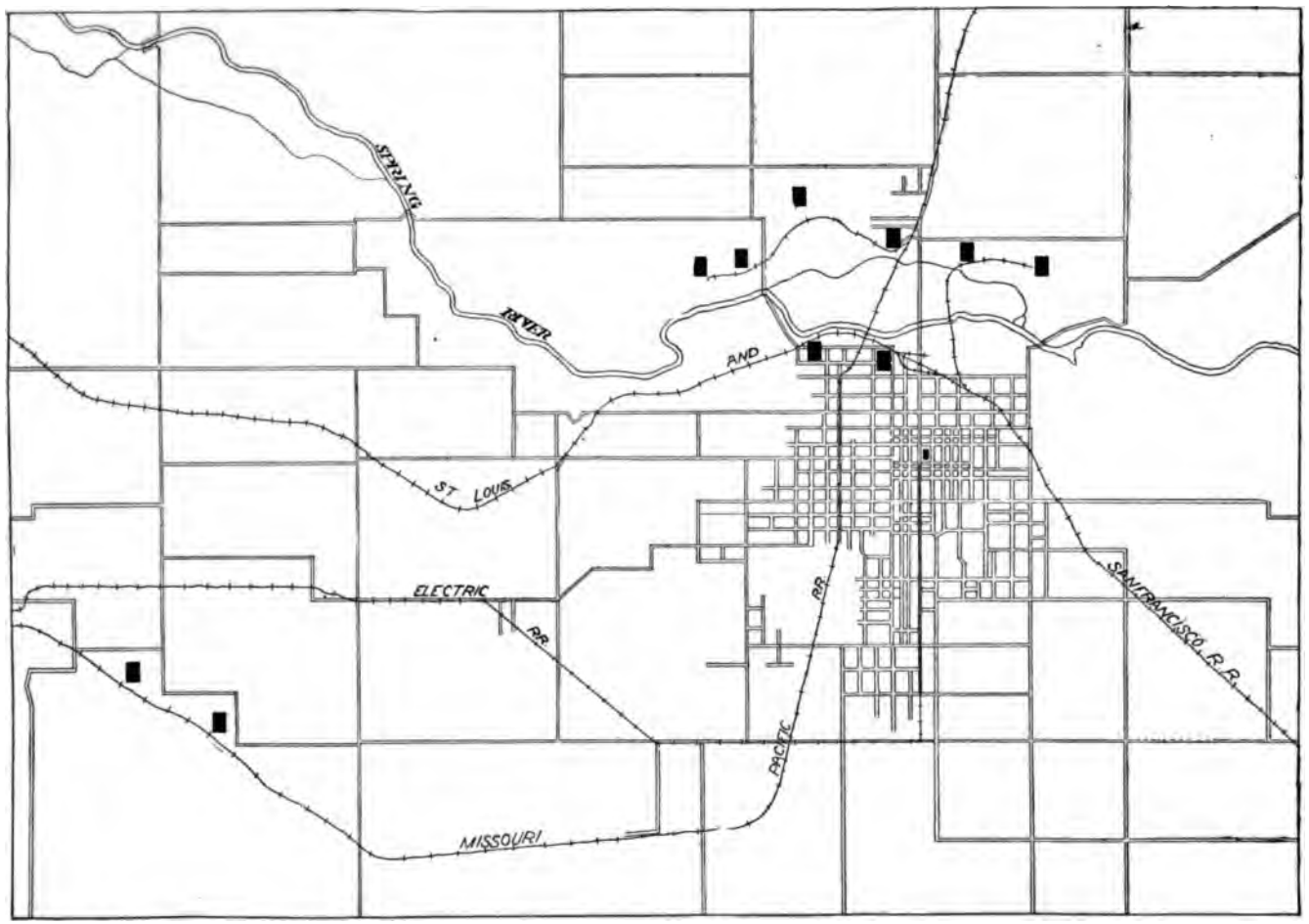
This quarry, which is located along the bluff about one mile west of Blackwater, on the Missouri Pacific railroad, is owned by H. Lauterbach and operated by Colyer Bros. of Kansas City. It has been operated each year since it was opened in 1891.

The stone is quarried along the side of the bluff for a distance of about 2,000 feet. The following is a section of the quarry from top to bottom:

10 ft.	Red clay and chert stripping.
10 ft.	Coarsely crystalline, buff limestone containing considerable chert.
25 ft.	Coarsely crystalline, light gray limestone. Upper portion splits into beds from one to two feet in thickness. Contains considerable chert, of which there is a two-foot bed near the middle. Suture joints occur throughout the ledge. Occasional cavities containing zinc and barite have been observed.
20 ft.	Medium grained, crystalline, blue limestone containing many flint nodules and suture joints.

The entire face is worked, the stone being crushed in a plant situated near the middle of the quarry. The rock is hauled to the crusher in dump carts. The stone is not screened after leaving the crusher, but goes directly to a large storage bin from which it is loaded into the cars.

This quarry is equipped with steam drills, a Gates crusher and other necessary machinery. From 70 to 100 men are employed throughout the year. The plant produces from 650 to 750 cubic yards of crushed stone per day.



Map showing location of quarries in the Carthage area. ■ Quarries.

CARTHAGE.

The most extensive limestone quarries in Missouri are located at Carthage, the county seat of Jasper county. Although a comparatively new industry at this place, it has increased so rapidly that within eighteen years it has become the center of limestone production in this State. To-day all of the quarries, with the exception of the Carthage Consolidated Co. and the Viernow and Meysenburg Lime and Cut Stone Co., are being worked to their utmost capacity and the Carthage limestone is fast becoming one of the most popular building materials in the middle west.

With the exception of the Vernon and Lime-kiln quarries, all of those in the immediate vicinity of Carthage, are north of the city, along the escarpment just north of Spring river. The Veron and Lime-kiln quarries are located just south of Spring river near the northwest limits of the city. In addition to this, two quarries have been opened about five miles southwest of the city. All of these are included within the Carthage area and the stone which is produced is known as Carthage limestone. The following is a list of the quarries in this area:

Carthage Marble and White Lime Co.
Carthage Stone Co.
Carthage Quarry Co.
Viernow and Meysenburg Lime and Cut Stone Co.
Spring River White Lime Co.
Spring River Stone Co.
Carthage Building Stone Co.
Myers Stone Co.
Carthage Consolidated Quarry Co.

For many years this stone was quarried by hand and used for foundations, caps and sills in buildings in and about Carthage. It was also used for bridge abutments on the Missouri Pacific railroad near the city. The first quarrying machinery was introduced about 1885, since which time the stone has gained an almost national reputation.

Geologically, this limestone belongs to the Burlington division of the Mississippian or Lower Carboniferous. The formation obtained its name from Burlington, Iowa, where it is typically developed. The Mississippian outcrops in a broad irregular belt across the middle of the State, in a northeast-southwest direction. Near the central portion of the State, it occurs as a narrow belt of limestone broadening both to the southwest and northeast where it covers extensive areas.

The typical Burlington formation usually consists of heavy beds of brown and gray to white, coarsely crystalline limestone. Abundant remains of mollusca and crinoidea occur in this formation, some portions of which are made up chiefly of the remains of crinoidea. From an economic standpoint, it is the most important limestone formation in the State, being extensively quarried at Carthage, Hannibal, Springfield, Phenix, Ash Grove, Peirce City, Walnut Grove, Osceola and other places. At Springfield, Ash Grove and Peirce City it is used chiefly for the manufacture of quicklime and at Hannibal, Phenix and Carthage it is quarried extensively for building stone.

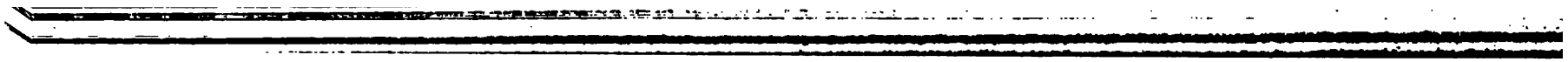
At Carthage this stone as it occurs in the quarry has a slightly bluish gray tint, the upper beds being whiter than those deep in the quarry. When cut and dressed, the stone is white. Nowhere is the color of the stone more uniform in the different quarries than in the Carthage area. The bluest tint observed in any of the stone was in blocks which had been quarried from the two lower channel cuts of the west opening of the Carthage Marble and White Lime Co. Even this stone, when rock-faced or sawed, has just enough of a blue tint to take away the monotony of a dead white. The faint blue tint gives the stone a life, which a dead white rock does not have. In uniformity of color this is the peer of limestones. In comparison, the Bedford, Indiana, stone is so far inferior as not to warrant consideration.

The calcite grains are closely interlocked, giving the stone strength and durability. A thin section of this stone, examined under the microscope, shows it to consist mainly of irregular grains of calcite of medium size, cemented together with a calcite matrix. The calcite has a dull grayish color in ordinary light. The faintest possible tinge of iron oxide was observed in two or three parts of the section. However, it is not sufficiently abundant to give color to the stone. No quartz or other minerals of importance were observed. No minerals that might cause discoloration through decomposition were observed. The freedom of the stone from impurities is shown by the following chemical analysis made in the laboratory of this Bureau.

Insoluble	.69
Oxides of Iron and Alumina (Fe_2O_3, Al_2O_3)	.21
Carbonate of Lime ($CaCO_3$)	98.57
Carbonate of Magnesia ($MgCO_3$)	.65
	100.12

Stratification planes, having the appearance of the joints in the cranium, which occur in this stone, were called suture joints by the earlier geologists. Later, these became known as stylolites. In this report we have chosen to call them suture joints. In the Carthage limestone,

CARTHAGE LIMESTONE (BURLINGTON).
Jasper County Courthouse, Carthage, Mo.



suture joints occur parallel to the bedding and are from two to twenty inches apart. They vary greatly in size, some of them being as much as four inches deep. The smallest of these joints are tight and the stone cannot be split along them as one might suppose. The larger of these joints are frequently open and along them the stone is usually easy to split. These seams injure the appearance of the stone when they occur on a sawed face. To avoid this, the stone is generally sawed parallel to the bedding and laid on edge in the wall. The so-called number one stone, or monumental stock, contains none but the very finest suture joints. An examination of the outcrops show that these joints will open after long exposure to the weather, separating the stone into thin layers.

In certain parts of the quarries, tar seams or joints occur in the stone. Some of the quarries are almost entirely free from them, while in others, they appear to be restricted to very limited areas. They consist of vertical or slightly inclined joints which contain bituminous material, which appears on the surface of the stone as a black line or dark streak. Stone containing these seams is rejected by contractors and consequently this discoloration may become a source of considerable loss.

Compared with the Bedford oölitic limestone, the Carthage stone is much more difficult to cut and dress. Two inches per hour is about the average work that can be done in sawing this stone. It has a much lighter and more uniform color than the Bedford limestone. It is considerably stronger than the Bedford stone, as is shown by the strength tests given in table in the appendix.

The stone polishes nicely and is used quite extensively in monumental work. The difficulty in obtaining large pieces free from suture joints is the greatest drawback to its use for monuments.

Lenticular and roundish nodules of flint occur in different parts of this formation. They are not scattered promiscuously through the stone, but occur at definite horizons in the formation. These nodules vary in size from several inches to three feet in their greatest diameter. Normal to the bedding planes, they are not usaully over ten inches in thickness. As a rule, they do not form a continuous or connected layer. The quantity of flint varies in different quarries. Occasionally a bed contains so much flint as to make the expense of quarrying very great. (See description of the old quarry of the Carthage Marble and White Lime Co.) The floor of most of the quarries is a bed of flint nodules. These beds of flint nodules do not occasion very great waste since the blocks of stone are usually lifted along them.

The Carthage limestone has no protective layer above it and solution has decomposed the stone along the jointing planes. Due to this process

of decomposition, the surface is usually very rough and bouldery. The open seams are filled with clay and are known throughout the district as mud seams.

Improved machinery is in use in all the quarries. The Sullivan improved Y channeler is being tried in a number of these quarries. This machine will channel upwards of 150 linear feet per day.

THE CARTHAGE BUILDING STONE CO.'S QUARRY.

The quarry operated by the Carthage Building Stone Co. is located a quarter of a mile west of the Spring River Stone Co.'s quarry. This company has been in operation about a year.

The quarry is situated near the base of a hill which rises gradually to the north. It has a south face 150 feet long and has been worked about 100 feet into the hill. It is expected to extend the quarry to the east so as to increase the available stone. At present the quarry face is 18 feet 6 inches in height and consists of three channel cuts 5 feet, 7 feet 6 inches and 6 feet in depth. Above the stone there is a stripping of about five feet of chert, clay and bouldery limestone. It is expected to make another channel cut below the present floor of the quarry. This will bring the bottom of the quarry near the level of the water in Spring river.

The stone from this quarry is very similar to that quarried in other parts of the area. It is a white, coarsely crystalline limestone, and free from impurities which might result in discoloration. Suture joints occur here the same as in the other quarries. There are no noticeable tar seams and very little flint has been encountered.

The quarry is equipped with two Sullivan Y channelers and a forty-ton derrick. A large modern mill has been erected containing six gang-saws, the largest of which will take a block 16 feet 10 inches long by 9 feet high. The other five gang-saws will take blocks 12 feet 6 inches long by 7 feet in height. The power to operate the plant is furnished by a 250-horse power boiler and 150-horse power engine. A fifty-ton traveling crane is used to move the stone in the cutting shed and onto the cars.

THE CARTHAGE CONSOLIDATED QUARRY CO.'S QUARRY

This quarry, which is located in the N. E. ¼ of the S. E. ¼ of sec. 11, T. 28 N., R. 32 W., was opened in 1895 by W. B. Myers who later sold it to the Carthage Consolidated Quarry Co. It has not been worked since 1900.

This quarry has a south and east face, the former of which is 300 feet and the latter 200 feet long. The following is a description of the channel cuts from top to bottom:

Carthage Building Stone Company's Mill, Carthage, Mo.

4 ft. 8 in.	Limestone, containing a number of prominent suture joints from six to fifteen inches apart. Between these are small suture joints.
4 ft.	Limestone, containing prominent suture joints one foot three inches from the bottom and three inches from the top.
8 ft.	Limestone in which the suture joints are from four to ten inches apart. Two very prominent ones occur eight inches and three feet from the top.

The major joints are open and strike N. 30° E.

The expense incurred by removing the two cherty ledges has caused this quarry to be abandoned for the present. Outside of these ledges, the stone is practically of the same quality as that in the other quarries. The first stone quarried at this place was used for bridge abutments on the Missouri Pacific railroad.

The west quarry is located in the N. E. ¼ of the S. E. ¼, sec. 32, T. 29, R. 31 W., about one-fourth of a mile southwest of the quarry owned by the Carthage Quarry Company. It consists of an irregular opening about 400 feet by 260 feet. The following is a description of the stone by channel cuts from the top to the bottom of the quarry:

0-8 ft.	Red clay and broken stone stripping.
6-9 ft.	Bouldery limestone having a mottled color due to bituminous material.
7 ft. 4 in.	Light gray limestone, containing suture joints from two to eight inches apart.
3 ft. 8 in.	White stone. Lower portion of one and one-half feet free from prominent sutures. Bed contains dries.
4 ft. 2 in.	White limestone. The lower two feet contains no suture joints of importance. Fourteen inches of this stone is practically free from them. In the remainder of the ledge, these joints are from two to eight inches apart. The stone splits along a prominent joint, containing blue shale, one foot from the bottom.
8 ft.	Bluish colored limestone, contains fine and coarse suture joints from two to fourteen inches apart. One of the prominent suture joints occurs two feet from the bottom.
4 ft. 6 in.	Blue limestone, containing two coarse suture joints two feet three inches from the bottom and eleven inches from the top of the ledge.
3 ft. 6 in.	Limestone, containing suture joints from two to ten inches apart.
8-16 in.	Layer of white chert.
2 ft. 6 in.	White, fine grained limestone containing a thickness of from twenty to twenty-four inches of No. 1 stone.

Below the floor of this quarry, good stone is known to occur, although none of it has been quarried. The quarry face contains an occasional fine suture joint perpendicular to the bedding. At present no stone is being quarried below the white chert layer.

The following are the maximum thicknesses of No. 1 stone that can be obtained from the different channel cuts when the stone is sawed across the bed:

CARTHAGE LIMESTONE (BURLINGTON).
Carnegie Library, Joplin, Mo.

West Mill of the Carthage Marble and White Lime Company, Carthage, Mo.

CARTHAGE LIMESTONE (BURLINGTON).

West quarry of the Carthage Marble and White Lime Company, Carthage, Mo.

1st (bottom cut) .....18 in.
2nd ....6-8 in.
3rd ....20 in.
4th ....20 in.
5th ....16 in.
6th—Rather irregular producer of No. 1. In places a thickness of 10 inches can be obtained.

The beds dip slightly to the north. Irregular open joints, filled with clay, strike northwest and extend into the quarry as far as the second channel cut above the flint bed.

At the northeast corner of the quarry the lower beds give evidence of being under slight stress. When making the opening or head cut north and south on each of the three lower channel cuts, it was found that as this cut deepened it closed perceptibly, and smaller bits were necessary to continue the work. The effect was noticed after the stone had been channeled from two to three feet from the top of the bed. The stone for about eighteen inches on each side of the channel cut showed many fine joints parallel to the bed.

The mills at both the east and west quarries are equipped with modern machinery for handling, sawing and dressing the stone. The east mill is equipped with gang-saws, a traveling crane, engines, boilers and other necessary machinery. The west quarry is equipped with an engine, boiler, gang-saws, rip-saws, derricks, hoists, etc. The quarry is equipped with channelers, derricks and such other machinery as is necessary to remove the stone.

This company has a mill in St. Louis, at which much of the stone used in that city is cut and dressed.

THE CARTHAGE QUARRY CO.'S QUARRY.

This quarry is located about one-half mile west of the east quarry of the Carthage Marble and White Lime Co. E. O'Keefe is president of the company, F. W. Steadly is secretary and treasurer and Martin A. McNerney is general manager. The company owns nine acres of land on which the quarry is situated.

The quarry consists of an irregular opening, having a north and south face of 175 feet and an east and west face of 225 feet. The stone is essentially the same as that obtained at the other quarries, being a coarsely crystalline, bluish gray to white limestone. The following is a description of the stone by channel cuts from the top to the bottom of the quarry:

2-8 ft. Bouldery limestone covered with clay and broken stone.
2 ft. Limestone, containing suture joints.
2 ft. 6 in. Limestone, containing a bed of chert nodules near the middle.

7 ft.		Limestone, containing a six inch bed of chert nodules at the top.
6 ft.	2 in.	Limestone, containing a coarse suture joint two feet from the base. Above this is a twenty inch bed of No. 1 stone containing a small suture joint.
4 ft.		Limestone having a coarse suture joint at the bottom and two of medium size near the middle of the bed. Above this is an eighteen inch bed of No. 1 stone, used for monumental purposes. Some very good stone is also taken from the lower part of the ledge.
3 ft.		Limestone having a very coarse suture joint twelve inches from the bottom. Above this is a sixteen inch bed of No. 1 stone containing one fine suture joint near the middle.
4 ft.	6 in.	Lowest ledge of limestone. The upper three feet two inches is very good stone from which blocks of No. 1 stone from twelve to fourteen inches in thickness can be obtained.

The floor of the quarry at this place consists of a layer of flint from sixteen to eighteen inches in thickness, underneath which occurs a good bed of limestone six feet thick. The character of the stone below this is not known.

The surface of the quarry is rough, due to solution of the limestone. One or two clay pockets were noted in the upper portion.

Occasional fine sutures and fine veins of calcite occur perpendicular to the bedding of the stone. Sutures were noted in the north portion of the quarry, which strike east and west. The calcite veins strike north and south. Occasional tar seams occur in the quarry, especially near the northeast corner.

Quarrying is now being carried on in the southwestern portion, where exceptionally good stone is being taken out.

The quarry and mill are both equipped with modern machinery, including a Sullivan Y and Wordwell channelers, derricks, steam pumps, gang-saws, rip-saws, hoists, boilers and engine. The quarry has a capacity of 1,000 cubic feet per day. It is operated all the year and employs on an average of twenty-five men.

THE CARTHAGE STONE CO.'S QUARRY.

The quarry of the Carthage Stone Company is located west of the west quarry of the Carthage Marble and White Lime Co., in the S. E. ¼ of the N. E. ¼ of sec. 32, T. 28, R. 31 W. It was opened in 1892 and has been operated continuously since that time. The company owns twelve acres of land. Curtis Wright is president of the company, J. W. Ground, vice-president, W. R. Logan, secretary and treasurer.

The quarry has a south face about 500 feet long. The stone is being quarried chiefly from the west end. Suture joints occur in the same manner as in the other quarries, and approximately the same thickness of No. 1 stone can be obtained. The presence of tar seams has occasioned the quarrying of a large quantity of stone which cannot be used for the

CARTHAGE LIMESTONE (BURLINGTON).
Col. William Phelps' Residence, Carthage, Mo.

1.

2.

CARTHAGE LIMESTONE (BURLINGTON).

Fig. 1. Quarry of the Carthage Quarry Company, Carthage, Mo.
Fig. 2. Quarry of the Carthage Stone Company, Carthage, Mo.

better class of buildings. A large number of these imperfect blocks are at present piled up in the quarry.

The stone is a white, somewhat coarsely crystalline, limestone and is similar in all respects to that found in other parts of this area.

The quarry has a clay and chert stripping of from two to five feet. There are very few joints and they seldom extend to the bottom of the quarry. Those which were observed had a strike of N. 60°-65° E. They are most abundant near the east end.

This quarry is equipped with a modern mill. The stone is quarried, dressed and cut with modern machinery, including channelers, hoists, derrick, gang-saw, engine and boilers. The company owns an electric plant and during the past nine years the quarry has been operated day and night. A portion of the stone is shipped in the rough to St. Louis where the company has a yard, at Gratiot and Theresa avenues, for cutting and dressing.

THE MYERS STONE CO.'S QUARRY.

This quarry, which is owned by Wm. Myers of Joplin and Frank N. Myers of Carthage, and operated by the latter, is located about three and one-half miles southwest of the Carthage court house, in sec. 12, T. 28, R. 32 W. It is just north of the Missouri Pacific railroad, with which it is connected by a spur. The company owns ten acres of land upon which the quarry is situated. The quarry was opened in 1902 and has a west face of 75 feet and a south face of 100 feet. It presents a vertical face of twenty-five and a half feet of stone covered with a thin stripping of clay.

The following is a description of the channel cuts from the top to the bottom:

4 ft.	Limestone, containing numerous sutures. This bed contains clay pockets which are connected with the surface. As this bed is worked into the hill these will gradually disappear.
8 ft.	Limestone, containing numerous suture joints. Near the middle of the bed a thickness of fourteen inches of stone, practically free from these joints can be obtained. Another thickness of from twelve to fourteen inches of clear No. 1 stone can be obtained near the base of the cut. The stone from this cut is not as good as that from the channel cuts below.
8 ft. 6 in.	Limestone, the upper part shows a thickness of from fifteen to seventeen inches of No. 1 stone; beneath this the suture joints are numerous.
4 ft.	Limestone, containing very many suture joints.
6 ft.	Limestone, in which a suture joint, three inches in depth occurs eighteen inches from the base of the ledge. Twelve inches above this, a large two inch suture occurs. Between these suture joints, the stone is solid giving a thickness of eighteen inches of perfect stone. The upper part of the ledge contains numerous small suture joints.

The lowest channel cut contains the best stone in the quarry. This cut contains the thickest bed of stone free from sutures which was observed in any of the quarries at the time this examination was made. The Federal building at Joplin was built out of stone from this ledge.

The stone in this quarry is free from tar seams. Clay pockets are troublesome in working the upper part of the quarry. However, they do not extend to the depth of the lower channel cut.

The quarry and mill are equipped with modern machinery, including a 65-horse power engine, 80-horse power boiler, three gang-saws, a steam hoist, Wordwell channelers and a large derrick.

THE SPRING RIVER STONE CO.'S QUARRY.

This quarry, which is located three-fourths of a mile northeast of Carthage, is owned by E. W. Johns, G. W. Stebbins and H. C. Johns, who operated under the firm name of The Spring River Stone Co. The company owns eleven acres of land on which the quarry is located. The quarry has a face of 300 feet along the south side of the escarpment. The east end of the opening has not been channeled. The quarry was opened in 1900.

The following channel cuts were being quarried in 1903:

4-8 ft.	Clay, chert and very cherty limestone. Stripping.
4 ft.	Limestone, showing large suture joints near the middle of the cut.
7 ft. 8 in.	Limestone, containing numerous suture joints from two to ten inches apart.
7 ft. 10 in.	Limestone, containing large suture joints. In the lower three feet of this stone, the suture joints are very fine. This cut contains an occasional flint nodule.
4 ft. 6 in.	Contains good No. 1 limestone. A layer of flint occurs along the top of the cut. Part of the face of this cut was covered with waste and water when the quarry was examined.

The stone from this quarry does not differ essentially from that quarried by the Carthage Building Stone Co. The stone is mainly free from tar seams. A few dries occur and strike about northeast. Joints occur from twenty to forty feet apart and strike N. 25° E. and N. 60° W. As a rule, these joints are open and filled with red clay.

The quarry is equipped with a modern mill and necessary machinery, including channelers, gang-saws, hoists, derrick, engine and boiler. The quarry is connected with the St. Louis and San Francisco railroad by a side track.

THE VIERNOW AND MEYSENBURG QUARRY.

This quarry is located in the S. E. ¼ of the S. W. ¼ of sec. 33, T. 29, R. 31 W., near the northwest limits of the city. It is just south of the St. Louis and San Francisco railroad and about a half a mile northwest of the Missouri Pacific railroad depot. The quarry was opened in 1891 and the company owns six acres of land upon which it is located.

CARTHAGE LIMESTONE (BURLINGTON).

The quarry has an east and west face of about 400 feet and a north and south face of 175 feet. The following is a description of the stone by channel cuts from the top to the bottom of the quarry:

2-8 ft.	Bouldery limestone, containing clay seams and irregular pockets at the surface.
6 ft.	Limestone, containing short tight seams and coarse suture joints near the middle of the bed. The lower portion of the ledge is good stone.
5 ft. 6 in.	Limestone, containing suture joints from two to eight inches apart. A coarse suture joint occurs fourteen inches from the bottom and fourteen inches from the top.
2 ft. 10 in.	Darkest colored limestone in the quarry. Contains suture joints

Two beds of finer grained stone than that in the section above described occur beneath the floor of the quarry. They are separated by a layer of chert nodules and the upper bed is capped with a two-foot layer of hard flint. These beds are not worked on account of the expense of removing the chert.

The quarry has been worked beyond the crest of the hill and consequently the face is decreasing in height and the stripping increasing. The stone contains bluish colored, tight seams which damage considerable of the stone. About thirty per cent. of the stone quarried is classed as No. 1.

Both the mill and quarry are equipped with necessary machinery, including channelers, derricks, gang-saws, engines and boilers. The output in 1900 was 18,000 cubic feet of dimension stone and 600 perch of rubble. The output in 1901 was 22,000 cubic feet of dimension stone and 600 perch of rubble. The quarry was not in operation during 1903.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of limestone from Carthage were tested in the laboratory with the following results:*

Specific Gravity		2.708
Porosity		1.344 per cent.
Ratio of Absorption		0.502
Weight per cubic foot		167. lbs.
Transverse Strength		2285.5 lbs. per sq. in.
Crushing Strength	(a)	14,270.6 lbs. per sq. in. on bed. 11,879. lbs. per sq. in. on edge.
	(b)	16,337. lbs. per sq. in. on bed. 15,396. lbs. per sq. in. on edge.
	(c)	12,741.3 lbs. per sq. in. on bed. 12,684. lbs. per sq. in. on edge.
	(d)	17,777. lbs. per sq. in. on bed.
Crushing strength of samples subjected to freezing test	(a)	13,382.7 lbs. per sq. in. on bed.
	(b)	15,865.0 lbs. per sq. in. on bed.
	(c)	13,921.0 lbs. per sq. in. on bed.

(a) Samples free from suture joints.
(b) Samples containing suture joints from ½" to ¾" in depth.
(c) Samples containing fine suture joints. Coarsely crystalline.
(d) Samples of free stone. Maximum crushing strength 20,261 lbs.

*Material furnished by the Carthage Marble and White Lime Co.

Three sets of specimens were used for determining the strength of the fresh and frozen samples, the results of which are given above. It will be observed that in the first case (a) the strength of the frozen samples was 887.9 pounds per square inch less than that of the fresh samples; in the second case (b) the frozen samples tested 472 pounds per square inch less than the fresh samples; and in the third case (c) the strength of the frozen samples was 1179.7 pounds more than that of the fresh samples. These tests were made upon stone which was free from suture joints and on pieces containing suture joints. The results seem to indicate that the stone suffers comparatively little injury from alternate freezing and thawing.

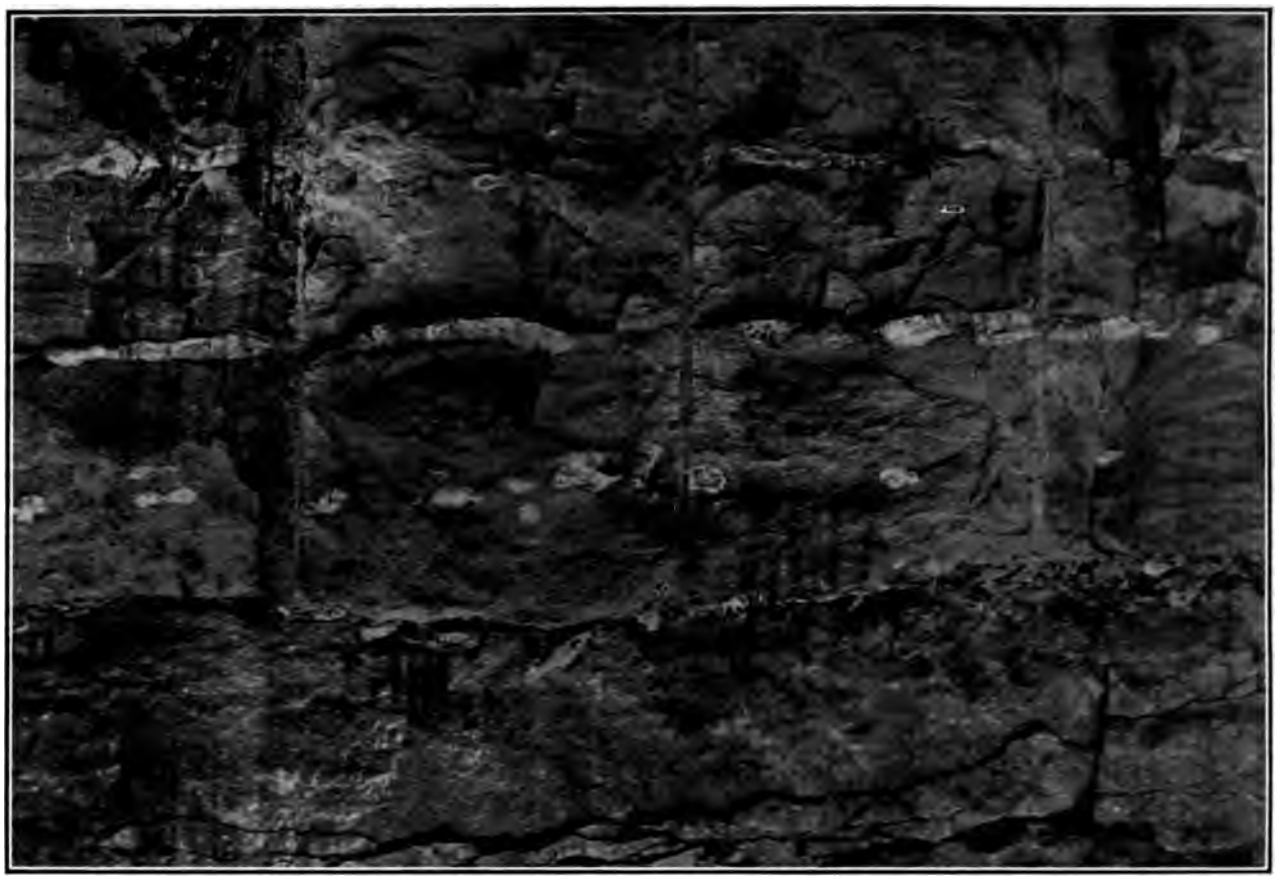
The slight difference between the ultimate strength of this stone on bed and on edge, as shown in all three cases, proves conclusively that there is no danger from placing the stone on edge in constructional work.

The weight of the stone as computed from the specific gravity and porosity determinations is somewhat lower than the weight of the stone as it comes from the quarry. A block containing about one cubic foot of stone, tested in the office of the Carthage Marble and White Lime Company, weighed 170 pounds. This, for commercial purposes, may be taken as the weight of the stone.

RÉSUMÉ.

The success attained by the different quarries in the Carthage area has resulted entirely from the excellence of the stone which occurs in that district. Carthage limestone is no longer an experiment. Its strength and durability have been established beyond the question of a doubt. The limestone from Bedford, Indiana, which is its chief competitor, is in no sense as desirable stone as that from the Carthage quarries. This stone has a crushing strength three times that of the Bedford limestone. When dry it weighs 167 pounds per cubic foot, while the Bedford, according to the report of the State Geologist of Indiana for 1896, weighs 154 pounds per cubic foot. A comparison of buildings constructed out of the two stones shows that while the Carthage stone is perfectly uniform in color and shows no discoloration with age, the Bedford limestone is not of uniform color and frequently exhibits a dark efflorescence, both of which are undesirable. The Carthage limestone is essentially free from those mineral constitutents which cause discoloration. Very seldom can one detect the presence of sulphide minerals, either fresh or altered.

The simple mineralogical composition of this stone renders it more capable of withstanding rapid changes in temperature than stone having a complex mineralogical composition. Samples subjected to very rigid



BURLINGTON LIMESTONE.
View showing the occurrence of flint. Drill holes five feet apart.

BURLINGTON LIMESTONE.
View showing the occurrence of Suture Joints (Stylolites).

freezing and thawing tests in the laboratory showed very little loss in their crushing strength.

There is an almost unlimited supply of limestone in this area and it is expected that, with proper management, in the next decade the industry will develop into very much larger proportions than at the present time.

Associated with the lead and zinc mines in the vicinity of Carthage, there are large quantities of chat which constitutes a source of supply of stone for macadam pavements which is unexcelled. This finely crushed flint and limestone is also used in the manufacture of artificial stone and brick, sewer pipe, granolithic sidewalks and curbing, and for many other purposes in combination with cement.

Buildings in which Carthage stone has been used.

BUILDINGS.	LOCATION.	PARTS.
Sedalia Library Building,	Sedalia, Mo.	Base and columns.
Bank of Harrisonville,	Harrisonville, Mo.,	Front.
State Normal Building,	Macomb, Ill.	Steps.
Stillwell Hotel,	Pittsburg, Kan.	
K. P. & G. Depot,	Kansas City, Mo.	Piers and trimmings.
W. J. Echols Building,	Ft. Smith, Ark.	Piers and trimmings.
Reynolds Davis & Co.,	Ft. Smith, Ark.	Front and trimmings.
Homestead Building,	Muscogee, I. T.	Front and trimmings.
Citizens Bank,	Muscogee, I. T.	1st Story and trimmings.
Bank of Muscogee	Muscogee, I. T.	1st Story and trimmings.
Leaver Building,	Muscogee, I. T.	Entrance and trimmings.
Spaulding Mercantile Co.	Muscogee, I. T.	Trimmings.
M. E. Church (South),	Muscogee, I. T.	Trimmings.
School Building,	Parsons, Kans.	Water table and trimmings.
Deacon, Elder & Deacon Bldg.,	Harrisonville, Mo	Trimmings.
Vinita National Bank,	Vinita, I. T.	Front.
Citizens Bank,	Checota, I. T.	Front.
Citizens Bank & Development Co.,	Wagoner, I. T.	Entrance piers and trimmings.
Citizens National Bank,	Chickasha, I. T.	Entrance.
Cotton Belt R. R. Hospital,	Texarkana, Ark.	Trimmings.
St. L. & S. W. & St. L. & S. F. Depot,	Jonesboro Ark.	Trimmings.
Frisco Hospital,	Springfield, Mo.	Trimmings.
1st National Bank,	Clarksville, Tex.	
Court House,	Ft. Dodge, Iowa.	Water table and sills.
Four School Bldgs.,	Chickasha, I. T.	Trimmings.
1st National Bank,	Maryville, Mo.	
State Asylum Bldg.	Nevada, Mo.	
Luchsinger Block,	Appleton City, Mo	
Chas. T. Johnston Residence,	Decatur, Ill.	
Crawford Co. High School,	Cherokee, Kan.	
St. Agnes Academy,	Ft. Smith, Ark.	
Ex-Confederate Monument,	Ft. Smith, Ark.	
Wm. Patterson Bldg.,	Pittsburg, Kans.	
Frisco Depot,	Jonesboro, Ark.	
J. P. Legett Residence	Carthage, Mo.	Complete.
W. Platt Residence,	Carthage, Mo.	Complete.

BUILDINGS.	LOCATION.	PARTS.
Jasper County Court House,	Carthage, Mo.	Complete.
Wm. Phelps Residence,	Carthage, Mo.	
Church,	Beaumont, Texas.	
St. Paul's Sanitarium,	Dallas Texas.	
Public Library,	Kansas City, Mo.	
Carnegie Library,	Joplin, Mo.	
Carnegie Library,	Carthage, Mo.	
Court House,	Jefferson City, Mo.	
Bates County Court House,	Butler, Mo.	
Government Bldg.,	Joplin, Mo.	
Court House,	Paola, Kans.	
Court House,	Herman, Mo.	

Numerous buildings in St. Louis, Kansas City and Sedalia, Missouri; Wichita, Parsons and Leavenworth, Kansas; Omaha and Lincoln, Nebraska, and Oklahoma City, Okla, have been built out of this stone.

CLARKSVILLE.

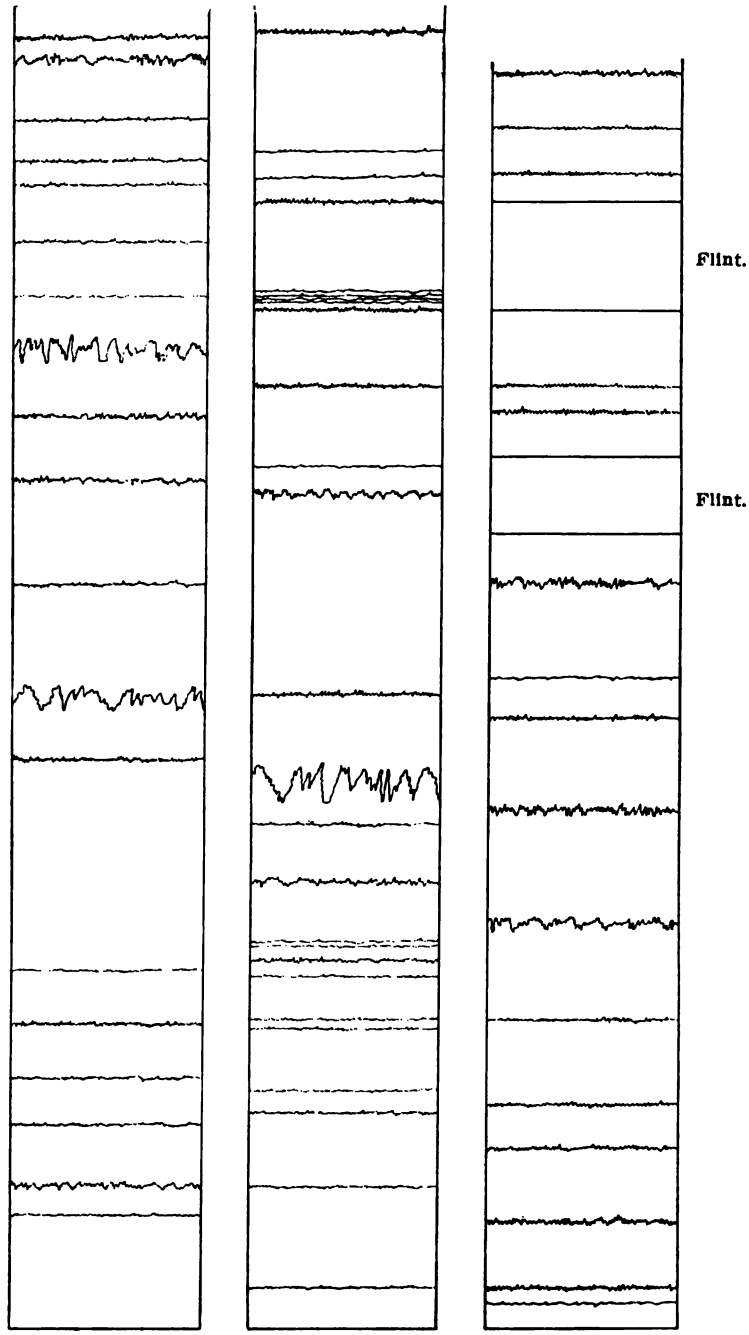
Two quarries, known as the Clifford and the Roberts, are located directly north of Clarksville. The Burlington railroad skirts the river close to the bluff upon which these quarries are located. A large part of the stone taken from them has been used by the government in the construction of retaining walls, break waters, etc., along the Mississippi river. It is also used for macadam and foundations. The quarries are worked intermittently.

THE CLIFFORD QUARRY.

This quarry is nearest to the city, being located near the western limits. It has a vertical face of 65 feet and extends along the bluff for a distance of 450 feet east and west. The following is a description of the beds from top to bottom of the quarry:

39 ft.	Very fine grained limestone, light yellow in color, in beds varying from six to eighteen inches in thickness. Beds are much broken up by jointing planes. These beds constitute what is known as the "Lithographic limestone."
2 ft. 3 in.	Blue arenaceous shale.
3 ft. 6 in.	Carbonaceous shale, very thinly laminated and stained with iron oxide near the top.
10 ft. 8 in.	Buff colored limestone having a sugary texture. Stained with iron oxide and containing small irregular cavities.
3 ft. 4 in.	Limestone, containing two layers of chert nodules, near the middle of the bed. Can be capped into three layers 1½ ft., 6 inches, and 1½ ft. respectively, in thickness.
4 ft. 4 in.	Light buff colored limestone. The upper bed, one foot in thickness, contains two layers of chert nodules. Can be capped into three one foot layers.
4 ft. 3 in.	Light buff colored limestone, very similar to the bed above. Contains small cavities but no chert.

The two principal joints strike N. 80° W and N. 70° E. They are far enough apart to permit the quarrying of dimensions of almost any



BURLINGTON LIMESTONE.

Occurrence of fine and coarse Suture Joints (stylolites). Scale 1 in.=1.25 ft.

ordinary size. The two lowest layers are well adapted for heavy masonry work.

The quarry is situated midway up the hillside, about sixty feet above the railroad and 160 feet below the summit. Above the perpendicular face of the quarry is a talus slope of 85 feet, which, in part, at least, consists of shale. This slope extends upward to the base of a cliff which is about six feet high. This cliff consists of beds of limestone, some of which contain large quantities of chert.

THE ROBERTS QUARRY.

This quarry is located in the S. W. ¼ of the S. E. ¼ of sec. 8, T. 52, R. 1 E., at the west end of the bluff on which the Clifford quarry is located. It is owned and operated by J. O. Roberts of Clarksville. The stone obtained here comes from near the top of the bluff and is of Burlington age.

The quarry has a vertical face of forty feet of limestone, containing very large lenses and layers of chert. There are from ten to twelve layers of chert nodules, which are from two to six feet apart. Most of the nodules are either round or lenticular in shape. Part of the face, mainly the upper beds, consists of stone having a light gray color. The lower twenty feet has a yellowish brown color.

The major joints strike east and west and north and south. The minor joints strike N. 55° W. and N. 80° E. The rock produced by this quarry has been used mostly by the government for breakwaters along the Mississippi river between Clarksville and Hamburg.

The beds are badly broken with the layers of chert nodules and it is doubtful if the stone can ever be quarried to advantage for dimensional stone. For rip rap and rubble it can undoubtedly be used very economically.

COLUMBIA.

A number of quarries have been opened in the vicinity of Columbia which are operated almost exclusively to supply the local market with building stone. These are all located in Burlington limestone and the stone does not differ essentially in any of the quarries inspected. The main difference is in the thickness of the beds and the qauntity of flint in the stone. The quarries now being operated are owned by Nichols Bros., George M. Richardson, J. H. Guitar and L. D. Gordon. Those operated by the first two are located north and northwest and those operated by the last two are south of the city.

THE GORDON QUARRY.

This quarry is located about one and one-half miles southeast of the city. The face is about one hundred feet long and twelve feet deep. The stone is coarse grained and crystalline, varying in color from gray to buff. There is some chert in the limestone, especially at the south end of the quarry. Inclusions of black carbonaceous shale occur near the middle of the quarry face. This quarry is not as active as the others in the vicinity of Columbia.

THE GUITAR QUARRY.

This quarry is located one and one-half miles south of the city. It consists of two openings, one on each side of a small north and south ravine. The face which is from 14 to 20 feet deep, consists of the following beds from top to bottom:

6 ft.	Broken chert and clay stripping.
8 ft.	Coarsely crystalline gray limestone containing many large lenticular nodules of flint.
6 in.	Layer of white flint.
6 ft.	Coarsely crystalline, dark gray, fossiliferous limestone. Near the west end of the quarry this bed contains small pockets of carbonaceous shale. One of the beds also contains large chert nodules. Near the bottom of the ledge the stone has a bluish color.

The major joints strike N. 50° E. and north and south. These joints are, frequently, not well defined and the stone breaks with difficulty along the bedding planes.

The stone contains some iron oxide which in places stains it brown. In the west opening, the stone has been worked six feet deeper than in the east. This bed is a coarsely crystalline, fossiliferous, blue limestone in which chert is very abundant.

The stone is being used in the new building which is being erected at the University farm.

THE NICHOLS BROS. QUARRY.

This quarry is located in the S. W. ¼ of the N. E. ¼ of sec. 1, T. 48 N., R. 13 W., one and one-half miles north of the city. It consists of four openings along the south bank of Bear creek, west of the Blackfoot road.

This quarry is owned by Mrs. Nancy W. Nichols and operated by C. H. and W. O. Nichols. It was opened in 1870, since which time it has been worked intermittently. Quick lime was at one time manufactured out of the stone, but not at present.

Only one of the openings is now being worked. As the stone is worked into the hill, the beds become too thick to be conveniently quarried

with hand tools. The stripping also increases in thickness; for these reasons the older openings have been abandoned, although they still contain stone of good quality. One of these openings shows the following succession of beds from top to bottom:

4-6 ft.	Broken limestone and clay stripping.
3 ft.	Gray, coarsely, crystalline, fossiliferous limestone. This bed splits in the middle in some parts of the quarry, while in others it splits into layers from four to eight inches in thickness.
2 ft. 6 in.	Gray and blue coarsely crystalline limestone; contains dries.
1 ft. 8 in.	Very coarsely, crystalline, blue limestone; contains dries.
4-6 in.	Layer of white chert.
3 ft. 3 in.	Blue, coarsely crystalline limestone. Suture joints occur six inches from the bottom and near the middle of the bed. The stone contains dries. On account of the heavy stripping and the thickness of the beds, this opening has not been worked for some time.

The opening which is now being worked is about one-fourth of a mile west of the road. It has a face about fifty feet long and ten feet high. The following is the succession of beds from top to bottom of the quarry.

1-3 ft.	Red clay stripping.
5 ft.	Gray, medium grained crystalline limestone. Occurs in beds from six to twelve inches in thickness.
3 ft.	Dark blue, fossiliferous, coarsely crystalline limestone. Splits into four beds about eight inches in thickness. The stone has a buff color along the bedding planes.

The stone is free along the bedding planes and consequently can be easily quarried. Should the quarry be extended into the hill, undoubtedly the bedding planes would become tight and would be more difficult to quarry.

The stone dresses nicely into caps, sills, ashler blocks and steps. The following prices were obtained for the stone in 1901: Rubble stone $1.00 per yard; crushed stone $1.35 per cubic yard.

A number of cistern and well covers have been cut out of this stone. For this purpose, the stone must be obtained in perfect pieces, five feet square. When dressed, these covers bring from $5.00 to $8.00 apiece.

THE RICHARDSON QUARRY.

This quarry is located in the S. E. ¼ of the N. W. ¼ of sec. 2, T. 48 N., R. 13 W., two and one-half miles northwest of the city. It is located on the east slope of a hill and has a face 200 feet long and about 11 feet high. The following is a section from top to bottom, measured at the south end of the quarry.

1 ft. 6 in.	White, coarsely crystalline, fossiliferous limestone. The weathered surface is rough.
1 ft. 4 in.	White, coarsely, crystalline limestone.

1 ft. 7 in.	Coarsely crystalline, light gray limestone with a suture joint near the middle of the bed, along which it may be split. Occasional short tight seams known as dries occur in this bed.
1 ft. 10 in.	Stone similar to that in the bed above. In some parts of the quarry this bed can be split into three layers.
2 ft.	Coarsely crystalline limestone, having a suture joint in the middle. Contains dries.
1 ft. 8 in.	Bluish gray, coarsely crystalline limestone, containing dries and "cutters."
1 ft. 2 in.	Blue to gray limestone, containing considerable chert.

The joints are not well defined. Two sets were noted, having a strike of N. 50° E. and north and south.

Short dry seams, some of which are colored red with iron oxide occur, especially in the lower beds. When colored, these seams are known as dries, and when not, as "cutters." They are harmful, in as much as they frequently cause the stone to break in a direction which is not intended in quarrying.

The stone is uniform, both in color and texture and occurs in beds which are of a convenient thickness for quarrying without machinery. Stone varying from four inches to two feet in thickness can be obtained. The different beds vary somewhat in thickness in different parts of the quarry. One bed was observed which varied in thickness from eight to fifteen inches within a distance of thirty feet.

The stone is apparently well adapted for ashler blocks, caps, sills and steps. Flagging and curbing are obtained from some parts of the quarry. This stone was used in Stevens College Chapel and the Benton public school. At present it is being quarried for use at the State University.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.620
Porosity	3.104 per cent.
Ratio of Absorption	1.225
Weight per cubic foot	158.7 lbs.
Crushing Strength	9828.5 lbs. per sq. in.
Crushing Strength of samples subjected to freezing test	9738 lbs. per sq. in.

These tests show that the stone is very little injured by freezing and thawing. The samples tested showed a difference of only 90.5 pounds per square inch.

EDINA.

THE VAUGHN QUARRY.

This quarry, which is owned and operated by John W. Vaughn, is located in sec. 36, T. 62 N., R. 12 W., about two and one-half miles southwest of Edina. It is worked intermittently for use in foundations and wells. The quarry is situated along the bank of a small creek and consists of an irregular but somewhat rectangular opening about 100 feet square. It was first opened in the creek bed where the stripping was very light. Since then, the quarry has been worked toward the hill and the stripping has increased until at present it is from six to ten feet thick. Underneath the stripping, about six feet of stone is quarried. This occurs in beds from two to four inches in thickness. It is a soft, very coarsely crystalline, gray to buff limestone, belonging to the Burlington formation. Small suture joints occur in the stone. The lower beds which are said to be from six to eight inches thick, were covered with debris at the time the quarry was inspected.

Although most of the stone can be lifted with a crow-bar and broken into regular blocks with a sledge, some dynamite has been used in loosening the larger blocks.

Another quarry has been operated, until recently, on this place. The stone is a coarsely crystalline, buff limestone, similar to that now being quarried. The opening was abandoned on account of excessive stripping.

ELM POINT.

THE MISSOURI PACIFIC RAILROAD CO.'S QUARRY.

This quarry, which was opened in 1894, is located in the N. E. ¼ of the S. E. ¼ of sec. 23, T. 47, R. 4 E., one mile north of the Missouri Pacific railway station. It is owned by the Missouri Pacific railroad and operated by John Ott. It is a sunken opening and has been worked 240 feet north and south and 60 feet east and west. The stone belongs to the St. Louis formation. The following is a description of the beds from the top to the bottom of the quarry:

2 ft. 7 in.	Dark gray finely crystalline limestone. Splits into two beds. At the north end of the quarry the stone contains nodules of soft iron oxide.
2-6 in.	Shaly limestone.
3 ft.	Dark gray, fine grained limestone. Splits into two beds.
2 ft. 4 in.	Dark gray, fine grained, compact limestone. Two six inch layers can be split from the top. The stone contains dries.

1 ft. 4 in. Two beds of fine grained, compact limestone. Breaks with an irregular fracture.
8 ft. 10 in. Thinly bedded gray limestone.
2 ft. 10 in. Two beds of very dark colored, fine grained limestone, containing geodes and nodules of calcite. Breaks with an irregular fracture.
8 in. Dark colored, fine grained limestone.
1 ft. 5 in. Thick bed of dark gray, fine grained limestone.
6 in. Stone similar to the bed above.
4 ft. Dark colored, granular, impure limestone.

This quarry is equipped with a small crusher and accessories, a derrick, steam hoist, steam drills and a steam pump.

HANNIBAL.

All of the stone quarried in the vicinity of Hannibal is limestone of Burlington age. The texture and color of the rock and the thickness of the beds vary locally in the different quarries, but, on the whole, there is a very close resemblance between the stone from all the quarries.

The most important quarries operated are the following: The Hannibal Lime Company, the Star Lime Company, the Empire Lime Company and the Waller Lime Company. About three miles south of the city the Atlas Cement Company have erected a factory for the manufacture of Portland cement, in the production of which the limestone and shale of the adjacent bluffs are used.

THE HANNIBAL LIME CO. QUARRIES.

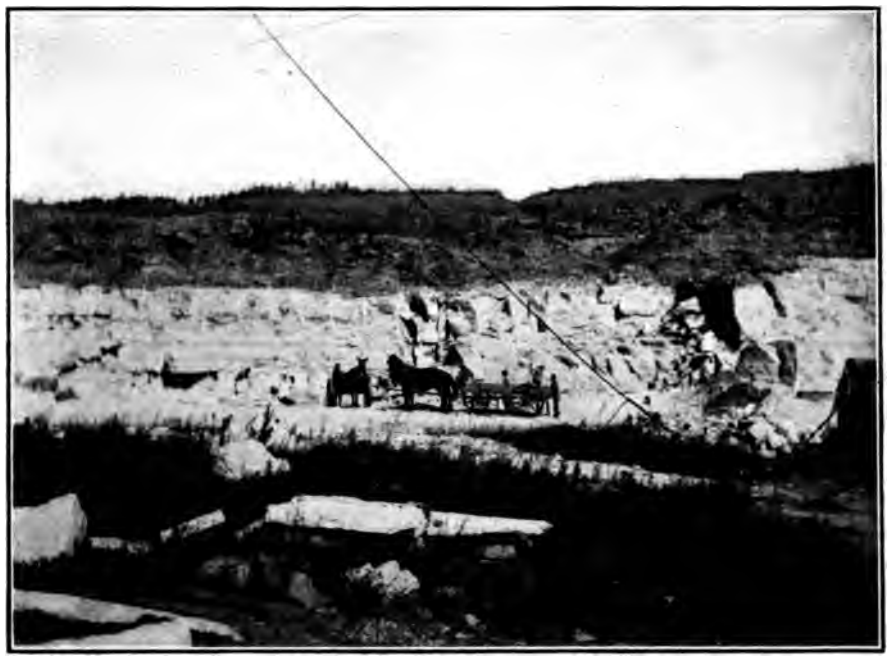
These quarries, which were until recently owned and operated by Munger Brothers, are now in the possession of a stock company of which Mr. John E. Jones, Jr., is manager. This company owns and operates two quarries, the most important of which is located at Bear Creek, about five miles west of Hannibal. The other is near the southern limits of the city.

The Bear Creek quarry has been operated very extensively, both for the manufacture of quicklime and for the production of building stone. The quarry has a south face extending east and west about 500 yards. The following is a description of the beds from the top to the bottom:

30 ft. Stripping. Thinly bedded limestone full of large chert nodules. Used for rip rap and railroad ballast.
7 ft. 10 in. White limestone. The upper foot of this bed, containing large cavities, is removed when quarried for dimensional stone. Suture joints occur in this bed.
3 ft. 6 in. Dark buff colored limestone. Contains chert nodules and abundant crinoid remains.
7 ft. White crinoidal limestone. Can be capped into two or three layers.
4 ft. 6 in. White, crinoidal limestone.

The major joints strike north and south. Three minor sets strike N. 40° E., N. 15° W. and N. 55° E. These joints are from ten to fifteen

1.



2.

BURLINGTON LIMESTONE.

Fig. 1. Mill and yards of the Hannibal Lime Company. Bear Creek, Mo.
Fig. 2. Quarry of the Hannibal Lime Company, Bear Creek, Mo.

feet apart, permitting the quarrying of large sized mill blocks. The layer of buff colored stone described in the section has only recently been met with in one part of the quarry. Prior to this the company had a working face of twenty-two feet.

Iron sulphide was not observed in the stone. The different beds have a very uniform color and texture. They are not easily capped, as the stylolitic bedding planes or suture joints are usually tight.

A very good grade of white building stone is obtained at this quarry. The stone is also used for sills, caps, steps and curbing. It has been used in the construction of the court house and public library, in Hannibal, as well as in numerous dwellings. A very good grade of white lime, known as the Bear Creek lime, is manufactured.

Steam drills and a channeler are used in quarrying the stone. Two gang-saws are used to cut it into blocks. The lime is burned in continuous kilns. At the time this quarry was inspected, the company had 80,000 cubic yards of limestone stripped ready for quarrying, which placed them in a position where they could furnish without delay almost any quantity of stone desired.

The stone from the small quarry, which the company operates just south of Hannibal, is not as good for building purposes as that at the Bear Creek quarry. It is used almost exclusively for the manufacture of lime.

None of the iron stained limestone is used in the manufacture of quicklime. The colored stone is crushed for macadam and broken for rip rap.

This quarry is equipped with steam drills, a Gates crusher and continuous lime-kilns. All sizes of crushed stone are manufactured. The company owns and operates a cooper shop in connection with the lime-kiln. The output is shipped mainly to Iowa, Nebraska, Kansas, Oklahoma and Indian Territory.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2 656
Porosity	5.031 per cent.
Ratio of Absorption	1.997
Weight per cubic foot	157.7 lbs.
Tranverse Strength	1,745.3 lbs. per sq. in.
Tensile strength	744.25 lbs. per sq. in.
Crushing strength	9286.3 lbs. per sq. in., on bed. 9915. lbs. per sq. in., on edge.
Crushing Strength of samples subjected to freezing test	8,975. lbs. per sq. in.

These tests indicate that the stone is very little, if any, affected by alternate freezing and thawing. The frozen sample tested 311.3 pounds per square inch more than those that were fresh.

The Star Lime Company, the Empire Lime Company and the Waller Lime Company are engaged largely in the manufacture of quicklime. They are large producers and their quarries will be described in detail in a subsequent volume on "Lime and Cement."

JOPLIN.

THE SHOAL CREEK QUARRY.

This quarry is located in the S. E. ¼ of the S. E. ¼ of sec. 29, T. 27, R. 33 W. At this place the Mississippian limestone outcrops for about a fourth of a mile along the escarpment formed by Shoal creek. The hill is precipitous and rises to a height of 160 feet above the flood plain of the stream. At several horizons near the top of the hill, the limestone forms almost vertical cliffs.

The summit of the hill is covered with a thin stripping of soil, underneath which ocurs fifty feet of rather thinly bedded limestone. None of the beds observed in this portion of the outcrop exceeds fifteen inches in thickness and most of them are much thinner. Directly underneath this thinly bedded limestone occurs the most important ledge, which, at the place examined, has a thickness of nine feet. It shows suture joints, which, from the weathered surface, appear to be very tight. The greatest thickness in this ledge, free from these parting planes, was found by measurement to be thirty inches. Near the top of this nine-foot ledge there are occasional pockets of chalk and chert.

Below this ledge occurs fifteen feet of thinly bedded limestone, underneath which is a second ledge three feet in thickness resembling in every respect the nine-foot ledge above described. Underneath this bed occurs twenty-five feet of what appears to be thinly bedded limestone. Underneath this is a three-foot ledge of what appears to be solid limestone.

Up to the present time this quarry has not been very extensively developed. The stone has only been used to a limited extent to supply the local market. It is said to be 99 per cent. calcium carbonate, and it is thought that it could be used successfully in the manufacture of quick lime, although there has been no practical demonstration of its suitability for this purpose. It is suitable for furnace flux and might be used as one of the constituents in the manufacture of Portland cement.

The nine-foot ledge is coarse grained and fossiliferous at the bot-

tom and dense and compact near the top. The stone has a very pleasing gray color which is uniform throughout all parts of the ledge. Iron sulphide, in any form, was not detected in any part of the exposure.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of limestone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.671
Porosity	1.129 per cent.
Ratio of Absorption	.423
Weight per cubic foot	165.1 lbs.
Transverse strength	1350.
Crushing Strength	11,870. lbs. per sq. in.
Crushing Strength of samples subjected to freezing test	8,111. lbs. per sq. in.

The samples used in these tests were not very carefully prepared and therefore the strength tests are thought to be somewhat lower than they should be. The wide difference between the strength of the fresh and frozen samples may be in a large measure attributable to this fact.

TAILINGS FROM THE LEAD AND ZINC MILLS.

The tailings from the Lead and Zinc Mills of this district, known as chats, are used in great quantities by the railroads for ballast and in the construction of concrete piers and abutments in bridges and culverts. They are also used extensively in the construction of macadam pavements and in granolithic walks and cement curbs and gutters. In the vicinity of Joplin, Webb City, Carterville, Carthage and Aurora, there are hundreds of thousands of tons of crushed flint and limestone available for these purposes.

One might suggest other uses to which these chats might be put. For example, it is thought that they might be used advantageously in the manufacture of artificial stone, electrical conduits and sewer pipe. The low price at which these tailings may be obtained makes them a very unimportant consideration in any product in which they might be used. They will prove, however, at some time, to be a very valuable asset to this district.

JUNGS.

THE THOMPSON & GRAY CO.'S QUARRY.

This quarry is located at Jungs Station on the Missouri, Kansas and Texas railroad about five miles west of St. Charles. It was opened in 1894 and has been worked intermittently since that time. It is situated along the bluffs just west of the M., K. & T. railway, and has a face

about 525 feet long. The following is a description of the beds from the top to the bottom of the quarry:

6 ft.	Loess stripping.
20-25 ft.	Limestone, in beds which are in part badly decomposed.
3 ft. 4 in.	Dark colored, argillaceous limestone. Very soft. The weathered surface shows a distinct efflorescence.
4 ft.	Finely crystalline, blue limestone. Splits readily along a shaly bedding plane one foot from the top. Also splits along similar seams near the bottom.
1 ft. 10 in	Dark colored, soft, argillaceous limestone. The weathered surface exhibits a decided efflorescence.
2-3 ft.	Gray to brownish, fine grained limestone. Contains chert nodules. Exhibits cross bedding near the north end of the quarry. The stone in this bed is good and ought to withstand freezing.
4 ft. 6 in.	Drab colored, argillaceous limestone. A white efflorescence shows on the weathered surface.
2 ft.	Drab colored, argillaceous limestone. A layer of flint nodules occurs six inches from the top. The stone is of poor quality but somewhat better than that immediately underneath.
5 ft. 6 in.	Drab colored argillaceous limestone. Is soft and decomposes rapidly when exposed to the weather.
19 ft.	Massive bed of fine grained limestone, through which are scattered somewhat larger crystals of calcite. The stone is very fossiliferous and varies in color from gray to blue. Cross bedding occurs in some parts of the bed. Dries, along which the stone is weathered to a yellowish buff color, occur in different parts of the bed.

The lowest ledge in this quarry contains by far the most suitable stone for building. The dries occasion considerable waste, but otherwise the stone can be worked into large mill blocks economically. The stone breaks with a straight fracture and is split with plugs and feathers. With the exception of two of the upper beds and the lowest ledge, the stone is crushed.

The quarry is equipped with a crushing plant, steam drills and a saw mill. The stone from this quarry was used in the county court house at St. Charles.

LA GRANGE.

There are extensive outcrops of stone along the river bluffs at La Grange, which have been quarried in a number of places for local building stone and rip rap. Quarries are owned at this place by the following named parties: L. Hagood, J. H. Brosi, Ried and Brosi and D. K. Oyster.

THE BROSI QUARRY.

This quarry is located in the N. E. ¼ of the S. E. ¼ of sec. 36, T. 61, R. 6 W., on the south side of South street, in the city of LaGrange. The face of the quarry is 150 feet long and 25 feet in height. The stone is a blue and buff, crystalline limestone, containing a large quantity of

disseminated chert. The chert destroys the value of the stone for constructional purposes, other than foundations. The chert and limestone, together, would make a very suitable road metal, although the limestone when used alone is too soft.

THE HAGOOD QUARRY.

This quarry is located in the N. E. ¼ of the N. W. ¼, sec. 25, T. 61 N., R. 6 W., about two miles northwest of the city. It is situated near the crest of a hill and has a face about 150 feet long and six feet in height. There is a stripping of three feet of clay, underneath which occur beds 8 in., 8 in., 6 in., 6 in., 1 ft. 6 in., and 1 ft. in thickness.

The stone is a fine to coarsely crystalline limestone which contains considerable argillaceous material. The color varies from a light gray to a yellowish buff. The stone in the two lower beds is somewhat softer than that in the remainder of the quarry.

The major joints strike north and south, N. 70° W., and N. 75° E. Most of these joints are open and frequently the walls are coated with a thin layer of travertine.

This quarry is owned by L. Hagood and operated by his son, Horace Hagood. It is worked intermittently. The stone is used chiefly for buildings in the vicinity of LaGrange.

THE OYSTER QUARRY.

A small quarry, about one-fouth of a mile west of the Burlington railroad near the south limits of the town, is owned and operated by Mr. Oyster. The working face of the quarry is about 150 feet long. The following is a description of the beds from the top to the bottom:

1-3 ft.	Red clay. Stripping.
3 ft.	Limestone. Thin beds five inches to one foot in thickness, containing numerous chert nodules. Badly broken by joints.
4 ft. 6 in.	Soft, yellow limestone, containing numerous chert nodules.
3 ft. 2 in.	Buff colored limestone, containing numerous lenses of chert. Upper half of the bed has a bluish color.
7 in.	Blue shale.
1 ft.	Dark colored, crystalline limestone. This is a solid bed and contains fossil crinoids.
3 ft. 6 in.	Yellowish gray limestone, having numerous chert nodules disseminated through it.
2 ft.	Dark blue limestone. Very few fossils. Can be split into two layers eighteen inches in thickness. The upper layer contains many chert nodules.
4 ft. 7 in.	Dark blue, coarsely crystalline limestone, containing many small chert nodules. The upper two feet can be split into beds from four to six inches in thickness.
2 ft.	Dark blue, coarsely crystalline limestone. Can be split into two beds about a foot in thickness.

This quarry was opened about 1899 and has been worked mainly for rip rap and ballast for the Burlington railroad. None of the stone appears to be suitable for ashler blocks, but foundation stone can be obtained from the quarry.

The major joints strike N. 30° E., practically parallel with the face of the quarry.

THE RIED & BROSI QUARRY.

This quarry is located in the same section of land as that owned by J. H. Brosi, being on the opposite side of South street. The face is thirty-five feet in height and the following is a description of the different beds from top to bottom:

2-5 ft.	Broken stone and clay stripping.
15 ft.	Blue and buff limestone in layers from eight to twelve inches in thickness, interstratified with beds of chert from four to eight inches thick.
6 in.	Blue shale containing many crinoid stems.
2 ft. 10 in.	Light gray, fossiliferous, crystalline limestone.
2 ft. 3 in.	Gray, crystalline, fossiliferous, medium grained limestone.
4 ft.	Bluish gray, crystalline, fossiliferous limestone, containing small cavities, calcite geodes and chert nodules.
6 in.	Shaly rock which weathers very rapidly.
1 ft. 10 in.	Blue, coarsely crystalline, fossiliferous limestone, containing many chert nodules.
5 ft.	Gray, coarsely crystalline cherty limestone.

The only stone in this quarry which is apparently free from chert nodules is found in the two beds immediately underneath the six-inch layer of blue shale. The stone from these beds can be cut and dressed into ashler blocks, caps, sills, steps, etc. The ends of the blocks which are broken across the bed, show pencil-like markings, caused by the fossils which are particularly abundant in the lower bed. The cherty limestone can only be used for rip rap and rough rubble.

When active, this quarry is operated during the summer months. About forty men are usually employed. The rubble stone is sold at 75c per perch. The stone has been used largely in river improvements.

LOUISIANA.

The following quarries are located in the vicinity of Louisiana: the C. C. Pratt quarry, situated at the west end of the city; the Hart quarry, southwest of the city; the Marble Head Lime Co.'s quarry, two miles north of the city; and the City quarry at the foot of Eighth street. The stone at all of the quarries, with the exception of the City, is of Burlington age and is situated at the top of the bluffs about 200 feet above the Mississippi river valley.

THE HART QUARRY.

This quarry, which is owned by Mr. Hart of St. Louis, was at one time a large producer of building stone, but at the present time it is not being worked.

The following is a description of the beds from top to bottom:

20 ft.	Very dark brown limestone in layers, varying in thickness, from one to two feet. Many large chert nodules. In places the brown limestone is not over two or three feet in thickness.
10 ft. 4 in.	Nearly white, crystalline limestone containing many remains of crinoids. Suture joints show conspicuously where the channeler has been used. The weathered face shows bedding planes from two to six inches apart.
9 ft. 4 in.	Light gray crystalline limestone. Can be split into beds from six inches to a foot in thickness.
3 ft. 3 in.	Buff colored limestone containing great numbers of crinoid remains The uppermost foot of this bed contains many small particles of iron oxide which give the stone a deep buff color.
3 ft. 6 in.	Light colored coarsely crystalline limestone. Abundant crinoid remains and a few large lenses of chert. This ledge can be capped into three layers.
3 ft. 6 in.	Limestone. Can be capped into three layers. Many large chert nodules.
4 ft. 4 in	Coarsely crystalline, buff colored limestone. Many fossil crinoids and a few small chert nodules. Can be capped into three layers 1½ ft., 1½ ft. and 1 ft. in thickness.
5 ft. 4 in.	Gray, coarsely crystalline limestone. Numerous crinoid remains.

The face of the quarry has been badly shattered by blasting and for this reason the stone does not show up as well for dimensional purposes as it otherwise might. The principal joints strike north and south and east and west. Minor joints strike N. 55° E. and N. 55° W. The quarry has a north face extending for a distance of 350 feet east and west. Steam drills and a channeler have been used in quarrying the stone. The quarry is also equipped with steel tracks and cars for removing the stone to the bottom of the hill.

About half way down the bluff, evidences of shale were found, but the talus is so thick that it completely covers the deposit. At the base of the bluff there is a bed of shale twenty feet thick. This same bed was observed along the creek, a half a mile west, where it is exposed along the base of the bluff to a depth of about thirty feet. The shale and limestone occurring together make this an inviting place to consider the possibilities of manufacturing Portland cement.

THE PRATT QUARRY.

This quarry, which is located a short distance west of the city limits, is owned and operated by C[illegible]ott. At present very little work is being done at the quarry, al[illegible]as been worked very extensively

in former years. The stone is used extensively for foundations. Formerly the quarry produced crushed and pulverized rock for ballast, macadam, concrete, glass, flux, etc. Quicklime was also manufactured. Steam drills, a Gates crusher, pulverizers and screens were used in quarrying and preparing the stone for the market.

The following is a description of the beds in the quarry from the top to the bottom:

1-5 ft.	Clay, stripping.
20 ft.	Limestone. This bed is split into thin layers, containing many large chert nodules. The thickness varies in different parts of the quarry.
8 ft. 6 in.	Light gray limestone. Bedding planes are from six inches to one foot apart. Stone is much broken by joints.
6 ft.	Nearly white, crystalline limestone.
4 ft. 3 in.	Buff colored limestone, containing an abundance of fossil crinoids.
6 ft.	Light gray, coarsely crystalline limestone, containing many crinoid fossils.
8 ft.	Dark buff colored limestone, containing large nodules of chert. The upper portion of the bed is much darker than the lower.
4 ft. 10 in.	Dark gray, coarsely crystalline limestone, containing fossil crinoids and occasional small calcite geodes.

The principal joints strike north and south and east and west. Two other less prominent sets strike N. 55° E. and N. 30° W. The stone has weathered along some of these jointing planes leaving irregular V-shaped seams, which are filled with clay. Such seams are known to the quarrymen as mud seams and are common to most of the limestone quarries in this region.

THE EIGHTH STREET QUARRY.

At the foot of Eighth street there is an exposure of forty feet of limestone, belonging to the Lithographic formation, which has been used for macadamizing the streets of the city. The city does not own a crushing plant and the stone is broken by tramps and prisoners which are lodged in the city jail.

This is the best limestone that can be obtained in this region for street paving and should be used more generally for this purpose.

MISCELLANEOUS QUARRIES.

Near the top of the bluff, in the north part of the city, is a quarry, from which a large part of the accessible stone has been removed. The stone belongs to the Burlington formation and corresponds very closely to that in the other quarries.

The Buffalo Creek quarry is located about a mile south of the depot and close to the Burlington railroad. The stone has been quarried mainly from the Niagara formation. It has not been worked for a great many years.

There are several quarries a few miles from the city which are worked intermittently to supply local demands. Their distance from the railroad, however, will probably prevent any extensive development.

MADGE.

The Madge Stone Co. and the Joplin-Elk River Stone Co. operate quarries located on the same hill east of the Kansas City Southern railroad at this place. Both quarries are at the same level and similar stone is taken out of both.

THE JOPLIN-ELK RIVER STONE CO.'S QUARRY.

This quarry is located on the north side of the hill referred to above. The same beds are worked as in the lower portion of the quarry of the Madge Stone Co. The quarry, which has been in operation about two years, has not been worked far enough into the hill to give the entire succession. The rock is very similar in quality to that quarried by the Madge Stone Co. The beds, which occur directly above the 7-foot, blue, shaly bed, are somewhat heavier than in the Madge Stone Co.'s quarry. They are used either for heavy bridge stone or capped into range and curbing. This company confines itself to the production of curbing, rubble, bridge abutments, etc. The quarry is connected with the Kansas City Southern railroad by side track and is equipped with two derricks and a hoist for handling the stone.

THE MADGE STONE CO.'S QUARRY.

This quarry has a west face of about 500 feet along the hill. The stone is fine grained, bluish limestone, lying in well stratified beds. The stone above the 7-foot shaly bed is coarsely crystalline and very fossiliferous. The following is a section of the quarry from top to bottom, showing the uses to which the stone in the different ledges is being put.

15 ft.		In beds from 2 to 8 inches in thickness. Upper nine feet is very flinty. Some flagging and rubble can be obtained from the heavier beds, but most of the stone is crushed.
	6 in.	Rubble.
1 ft.		Footing, bridge and range.
	8 in.	Footing and some range.
1 ft.		Footing, bridge and range.
	9 in.	Footing and bridge with some rubble.
	8 in.	Footing and range.
	4 in.	Flagging.
1 ft.	3 in.	Bridge. Can be capped six inches from top.
	4 in.	Rubble and flagging.
	10 in.	Footing and some range.

1 ft.	1 in.	Bridge. Bed contains suture joints.
	8 in.	Footing.
	7 in.	Rubble.
1 ft.	11 in.	Used mostly for bridge stone.
1 ft.		Footing and bridge. Caps seven inches from the bottom.
1 ft.	4 in.	Footing, bridge and rubble. Caps seven inches from top and six inches from bottom.
	6 in.	Curbing, light footing and rubble.
	7 in.	
	11 in.	Bridge, footing and rubble.
1 ft.	7 in.	Rubble. Shows small suture joints.
	10 in.	Bridge stone and footing.
	0 in.	Footing.
	6 in.	Rubble.
2 ft.		Bridge stone. Also crushed. Contains nodules of pyrite.
7 ft.		Bluish colored stone, disintegrates rapidly because of shaly layers and bedding planes. Crushed.
	6 in.	Curbing and rubble.
1 ft.		Caps into three 4 inch flagging. Occasionally used for bridge stone.
1 ft.	2 in.	Bridge and footing. Caps along clay seams four inches from the bottom.
1 ft.	5 in.	Bridge stone and some range. Can be capped five and ten inches from the bottom.
	7 in.	Range and curbing.
	7 in.	
1 ft.	7 in.	Bridge and some range. Bed contains iron sulphide. Splits into two beds twelve and seven inches in thickness.

The major joints strike N. 5° E. and are from 25 to 30 feet apart. A second set, also prominent, strikes east and west. These joints greatly facilitate quarrying operations.

The waste of the quarry and the thin beds in the upper part of the section are crushed for macadam and railroad ballast. The lower portion beneath the seven-foot bed of bluish stone is the most valuable in the quarry. The stone in these beds is quarried by means of plugs and feathers. It breaks easily into blocks which can be used for range, curbing and bridge work.

This quarry has been in operation about five years and employs from ten to forty men. The quarry is equipped with a No. 3 Gates crusher, 35-horse power engine, 40-horse power boiler, two steam drills and two derricks.

MONROE.

THE DIRIGO QUARRY.

This quarry, which is located two and one-half miles south of the city, in the S. E. ¼ of the N. E. ¼ of sec. 36, T. 56 N., R. 8 W., is owned and operated by J. C. Dirigo of Monroe City. It was opened in 1895 and has been operated from May until November each year since. All of the stone is used locally. It belongs to the Burlington formation. The following is a description of the beds from top to bottom:

10 ft.	Broken chert and clay stripping.
5 ft.	Light gray, coarsely crystalline limestone, containing suture joints from six to twelve inches apart. These joints are tight and the stone does not split along them. The bed may be split into three layers 1′ 6″, 2′ 6″ and 1′ in thickness.
1-6 in.	Layers of chert nodules.
6 ft.	Limestone, similar to that in the five foot bed. The suture joints are not so abundant as in the ledge above. The lower portion of this bed is very coarsely crystalline, and somewhat softer than the upper part.

The stone is very free from iron oxide and evidently contains no pyrite. It has a pleasing uniform, light gray color and works well into ashler blocks, caps, sills, etc. The suture joints mar the appearance of the stone, and in order to obviate this defect, the blocks must be laid on edge.

The heavy beds of limestone terminates abruptly at the north end of the quarry, being replaced by white shale and broken chert, which occur at what is known as the "back seam," which strikes N. 30° E. and dips 45° S. E. North of the opening above described, are two others that were operated several years ago. These openings exhibit a number of thin beds of limestone, interstratified with layers of chert. Cavaties in a thick, dark brown bed at the base of these openings contain pseudomorphs of calcite after marcasite.

These two openings, which are now abandoned, were worked on account of the thin beds, which could be quarried with comparative ease.

MONTGOMERY CITY.

Two small quarries, located west of the city, are owned and operated, respectively, by J. P. Grennen and J. B. Grennen. The quarries are located in limestone of Burlington age. The market for this stone is entirely local.

THE J. P. GRENNEN QUARRY.

This quarry is located two and one-half miles west of the city. It has a face 125 feet long and twenty feet high. With the exception of two feet of soil stripping at the top, the face consists entirely of coarsely crystalline, gray and buff, fossiliferous limestone. Chert nodules are disseminated throughout the stone and suture joints are very common. The beds are very thick and the stone must be removed by blasting. It is difficult to obtain either rubble or common building stone.

The quarry is equipped with a No. 3 Austin portable crusher, in which the rock is crushed into two sizes, used chiefly for macadam.

THE J. B. GRENNEN QUARRY.

This quarry is located a quarter of a mile southwest of the J. P. Grennen quarry. The stone occurs in beds from four to twelve inches in thickness. That in the lower beds has a bluish color in the center with a buff color next to the bedding and jointing planes. The stone is very coarsely crystalline, especially in the upper beds.

This quarry has not been worked very deep and consequently the beds are not as solid as they will be farther in the hill. The stone is well adapted for foundations and other parts of buildings.

MT. VERNON.

A number of small quarries have been opened in the vicinity of Mt. Vernon, but they are only operated intermittently to supply local demands. They are all located along a range of bluffs north of the city, and in limestone of Burlington age. The color, texture and hardness of the stone is practically the same in all the quarries. They all contain too much chert to warrant extensive development. The principal quarries are owned by R. O. Davis, H. Brumback and W. N. Gibbs. Besides these, there are a number of less importance.

THE DAVIS QUARRY.

This quarry, which is located one mile west of Mt. Vernon, is owned and operated by R. O. Davis. It has a face 125 feet long and 25 feet in height. The following is a description of the beds from top to bottom:

4-6 ft.	Chert and clay stripping.
4 ft.	Coarsely crystalline, gray limestone. Suture joints occur one ft. from the bottom and near the top. Dries are quite prevalent in this bed.
5 ft. 6 in.	Bluish gray, coarsely crystalline limestone. A layer of chert nodules occurs eighteen inches from the top and along this, the bed will split. Suture joints occur at the base of the chert layer and two feet from the bottom of the bed.
5 ft. 4 in.	Consists of interstratified beds of coarsely and finely crystalline limestone. This stone contains large chert nodules, except in the upper eighteen inches, which is coarse grained.
2 ft.	Very coarse grained, crystalline, fossiliferous, gray limestone, containing very little chert and free from suture joints.
6 in.	Layer of chert nodules.
3 ft. 6 in.	Coarse grained, crystalline, bluish gray limestone, having flint nodules along the bottom. The greater part of this bed is free from chert. Suture joints occur near the middle of the ledge.

This stone, which has the appearance of that from Phenix, has been used for caps, sills, monument bases, etc. The lowest bed is the best in the quarry and from it can be obtained large blocks free from chert. The

stone used in the arches and columns of the court house, at this place, was obtained from this quarry. The remainder of the building is constructed of limestone from Phenix. So closely do these two stones resemble each other that it is almost impossible to distinguish them apart in the building.

THE BRUMBACK QUARRY.

This quarry is located one-half mile north of the city. It is situated well up on the hillside and consists of two openings, one above the other. In the upper opening, there is exposed a 4½ foot bed of stone which contains dark colored suture joints. The second opening is about fifteen feet below the upper one and a little to the west. A two-foot ledge is being quarried in this opening, the stone being used mainly for curbing. This bed, which is split with plugs and feathers, does not break very evenly and consequently is expensive to work. The curbing, however, is of excellent quality. This quarry is not worked deeper on account of the flint contained in the underlying beds of limestone.

THE GIBBS QUARRY.

This quarry is located across the road west of the Brumback quarry. The stone is essentially the same as that obtained from the other quarries. It contains considerable disseminated chert, which is the chief drawback to its development.

MISCELLANEOUS QUARRIES.

Two other quarries have been operated in this neighborhood. John Fenton owns one a half a mile west of the Davis quarry, in which the stone is essentially the same as that in the Davis quarry. Two and one-half miles east of the city, there is a small quarry owned and operated by Mr. Stewart. Two ledges of bluish gray limestone containing very little flint occur at this place.

The great quantity of flint renders extensive development impracticable. Where free from flint, the stone has all the appearance of being strong and durable. A good, strong, white lime can be burned out of this stone.

NAPTON.

Three quarries, owned respectively by Mrs. L. E. Tichenor of Napton, H. W. Kolkmeyer of Jefferson City and A. Olson of Marshall, are operated at this place. The quarries are located in sec. 2, T. 49 N., R. 20 W., just northeast of the village of Napton. They are situated along the crest of adjacent hills, the stone being obtained from beds of

This quarry was opened about 1899 and has been worked mainly for rip rap and ballast for the Burlington railroad. None of the stone appears to be suitable for ashler blocks, but foundation stone can be obtained from the quarry.

The major joints strike N. 30° E., practically parallel with the face of the quarry.

THE RIED & BROSI QUARRY.

This quarry is located in the same section of land as that owned by J. H. Brosi, being on the opposite side of South street. The face is thirty-five feet in height and the following is a description of the different beds from top to bottom:

2-5 ft.	Broken stone and clay stripping.
15 ft.	Blue and buff limestone in layers from eight to twelve inches in thickness, interstratified with beds of chert from four to eight inches thick.
6 in.	Blue shale containing many crinoid stems.
2 ft. 10 in.	Light gray, fossiliferous, crystalline limestone.
2 ft. 3 in.	Gray, crystalline, fossiliferous, medium grained limestone.
4 ft.	Bluish gray, crystalline, fossiliferous limestone, containing small cavities, calcite geodes and chert nodules.
6 in.	Shaly rock which weathers very rapidly.
1 ft. 10 in.	Blue, coarsely crystalline, fossiliferous limestone, containing many chert nodules.
5 ft.	Gray, coarsely crystalline cherty limestone.

The only stone in this quarry which is apparently free from chert nodules is found in the two beds immediately underneath the six-inch layer of blue shale. The stone from these beds can be cut and dressed into ashler blocks, caps, sills, steps, etc. The ends of the blocks which are broken across the bed, show pencil-like markings, caused by the fossils which are particularly abundant in the lower bed. The cherty limestone can only be used for rip rap and rough rubble.

When active, this quarry is operated during the summer months. About forty men are usually employed. The rubble stone is sold at 75c per perch. The stone has been used largely in river improvements.

LOUISIANA.

The following quarries are located in the vicinity of Louisiana: the C. C. Pratt quarry, situated at the west end of the city; the Hart quarry, southwest of the city; the Marble Head Lime Co.'s quarry, two miles north of the city; and the City quarry at the foot of Eighth street. The stone at all of the quarries, with the exception of the City, is of Burlington age and is situated at the top of the bluffs about 200 feet above the Mississippi river valley.

THE HART QUARRY.

This quarry, which is owned by Mr. Hart of St. Louis, was at one time a large producer of building stone, but at the present time it is not being worked.

The following is a description of the beds from top to bottom:

20 ft.	Very dark brown limestone in layers, varying in thickness, from one to two feet. Many large chert nodules. In places the brown limestone is not over two or three feet in thickness.
10 ft. 4 in.	Nearly white, crystalline limestone containing many remains of crinoids. Suture joints show conspicuously where the channeler has been used. The weathered face shows bedding planes from two to six inches apart.
9 ft. 4 in.	Light gray crystalline limestone. Can be split into beds from six inches to a foot in thickness.
3 ft. 3 in.	Buff colored limestone containing great numbers of crinoid remains The uppermost foot of this bed contains many small particles of iron oxide which give the stone a deep buff color.
8 ft. 6 in.	Light colored coarsely crystalline limestone. Abundant crinoid remains and a few large lenses of chert. This ledge can be capped into three layers.
3 ft. 6 in.	Limestone. Can be capped into three layers. Many large chert nodules.
4 ft. 4 in	Coarsely crystalline, buff colored limestone. Many fossil crinoids and a few small chert nodules. Can be capped into three layers 1½ ft., 1½ ft. and 1 ft. in thickness.
5 ft. 4 in.	Gray, coarsely crystalline limestone. Numerous crinoid remains.

The face of the quarry has been badly shattered by blasting and for this reason the stone does not show up as well for dimensional purposes as it otherwise might. The principal joints strike north and south and east and west. Minor joints strike N. 55° E. and N. 55° W. The quarry has a north face extending for a distance of 350 feet east and west. Steam drills and a channeler have been used in quarrying the stone. The quarry is also equipped with steel tracks and cars for removing the stone to the bottom of the hill.

About half way down the bluff, evidences of shale were found, but the talus is so thick that it completely covers the deposit. At the base of the bluff there is a bed of shale twenty feet thick. This same bed was observed along the creek, a half a mile west, where it is exposed along the base of the bluff to a depth of about thirty feet. The shale and limestone occurring together make this an inviting place to consider the possibilities of manufacturing Portland cement.

THE PRATT QUARRY.

This quarry, which is located a short distance west of the city limits, is owned and operated by C. C. Pratt. At present very little work is being done at the quarry, although it has been worked very extensively

The second opening referred to has a face seventy-five feet long. The stone is very much the same as that in the upper part of the first opening. The beds contain shaly parting planes, along which there are many fossils. This stone is apparently as desirable as that in the former opening, although it has not been quarried very extensively.

The third opening has a face 125 feet long and 30 feet high. The lower beds in this opening are a few feet above those in the opening first described. The following is a description of the beds from top to bottom:

0-2 ft.	Soil stripping.
10 ft.	Coarsely crystalline limestone.
12 ft.	Dark brown, fine grained, fossiliferous limestone. The stone is separated by thin seams of dark shale into layers from two to four inches in thickness.
1 ft. 7 in.	Dark gray, crystalline limestone containing numerous fossils along the bedding planes. Splits seven inches from the top.
3 ft. 6 in.	Dark gray, fossiliferous limestone, containing shaly parting planes from two to six inches apart. The fresh stone splits easily a foot from the bottom.
3 in.	Hard blue shale.
2 ft.	Blue, crystalline limestone separated into two beds by a thin layer of shale.

These beds increase in thickness as they are worked into the hill where the weather has not had an opportunity to open the bedding planes. The shaly planes make the stone susceptible to injury from weathering.

The stone has been used locally for caps, sills, foundations, sidewalks, crosswalks, curbing and to some extent for coursing. The two lower ledges in the third opening are best adapted for the latter purpose. A number of the ledges contain stone suitable for curbing, sills, etc. The quarries are worked intermittently to supply the local demand.

NOEL.

Three quarries are operated at this place. Most of the strata found in the quarry of the Madge Stone Co., described on a previous page, occur at all of the quarries. The strata above and including the seven-foot bed, have been removed by erosion at this place, leaving only the lower part of the section. The following quarries are being operated south of the city: The John P. Hughes quarry, the Armstrong and Cravens quarry and the Railroad quarry.

THE ARMSTRONG AND CRAVENS QUARRY.

This quarry, which is operated by James Armstrong and C. M. Cravens, is located about one mile south of Noel, just east of the Kansas City Southern railroad. The quarry, which was leased for five years from H. Hazelbaker, has been in operation about three years. The lease covers

a west frontage of 574 feet, the company having now worked a distance of 300 feet. The following is a section from top to bottom of the quarry:

4 ft. 6 in. Gravel and dirt stripping.
2 ft. Shelly, broken stone.
12 in. Solid bed, very difficult to cap. Used for bridge work.
10 in. Caps into two 5-inch layers used for curbing. Bed varies in quality; portions being of no value.
1 ft. 2 in. Caps easily into 6 and 8-inch curbing.
12 in. Makes 5-inch and 4½-inch curbing.
1 ft. 8 in. Caps into three equal layers.

The stone is all finely crystalline and has a slightly bluish color. Practically the entire output is curbing, which is shipped mainly to Kansas City. The top ledge and second ledge from the bottom are rather brittle and easier to work than the remaining beds. Open joints filled with clay strike N. 70° E. and occur from 40 to 60 feet apart. No joints at right angles to this direction have been encountered. From ten to twenty men are employed in this quarry. It is equipped with two steam drills, two hoists and three derricks. The company has offices and yards at 202 Oak street, Kansas City.

THE JOHN P. HUGHES QUARRY.

This quarry, which is located just west of the Kansas City Southern tracks, three-fourths of a mile south of town, is operated chiefly for the production of bridge abutments. The following is a section from the top to the bottom of the quarry:

8 ft. Shale and rough stone. Stripping.
12 in.
12 in. Solid beds, finely crystalline, bluish gray limestone.
14 in.
12 in.
10 in. Brittle limestone, contains small crystals of pyrite. Caps four inches from top.
1 ft. 8 in. Bed shows considerable iron sulphide in small crystals. Contains a number of small shale seams parallel to the bedding. Caps six inches from the top.

The beds are generally separated by thin layers of blue shale. When first quarried and left to season in the sun, the stone from the lower ledge is very liable to crack. This does not occur if the stone is placed in an abutment before seasoning. Open joints filled with clay strike N. 20° E. and N. 85° W. These joints, which are from 60 to 100 feet apart, are a great help in quarrying. It is impossible for the stone to work tight where these occur. The quarry has been operated about two years and an area 200x100 feet has been covered. Twenty-five men are employed. All the stone is cut and dressed at the quarry ready to be placed in the bridge.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.711
Porosity	.85 per cent.
Ratio of Absorption	.231
Weight per cubic foot	168.4 lbs.
Crushing Strength	24,661.5 lbs. per sq. in. on bed. 25,576.0 lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing tests	20,472 lbs. per sq. in.

These tests show that this is one of the strongest limestones in the State, only being surpassed by that from Kesterson's quarry at Jackson. It is interesting to note that this stone apparently suffered a loss in strength of 4,189 pounds through alternate freezing and thawing. These specimens were carefully prepared from the same block and the loss of 15 per cent. in strength must be chiefly attributed to the effect of the freezing.

THE RAILROAD QUARRY.

The Kansas City Southern railroad owns a quarry located just east of the railroad, joining the Armstrong and Cravens quarry on the south. It has a west face about 330 feet long and has been worked to the east 240 feet. The stone is similar in all respects to that in the adjoining quarries. The stone, which is directly underneath the stripping of from two to six feet of gravel and clay, is sound and good. The quarry has been in operation about four years. The principal output is stone for bridge abutments. Two derricks, two drills, a steam hoist and a boiler are used in quarrying and handling the stone.

OZARK.

Two quarries are located in the vicinity of this city, which are owned respectively by Mr. T. Reives and Mr. Henry Spiece. The stone from the Spiece quarry is used exclusively in local buildings, while that from the other quarry is used in the manufacture of curbing and flagging, which are shipped to Springfield and other cities in Southwest Missouri.

THE REIVES QUARRY.

This quarry, which is located in the Finley creek bottom, one and one-half miles north of Ozark, is operated by W. R. Sims of Ozark. The quarry has an east and west face of 600 feet and a north and south

face of 75 feet. The following is a description of the beds from top to bottom:

2 ft.	Soil stripping.
3 in.	Finely crystalline, gray limestone.
7 in.	Finely crystalline, blue limestone. Where weathered, this stone has a buff color.
7 in.	Blue, fine grained limestone. Splits into two layers which make good light curbing.
8 in.	Finely crystalline, compact, blue limestone. Very brittle, but works well for range and coursing. Contains occasional chert nodules.
6 in.	Medium grained, blue limestone, having a conchoidal splintery fracture.
10 in.	Coarsely crystalline, blue limestone. Splits six inches from the bottom and works well into heavy curbing and bridge caps.
3 in.	Fine grained, tough limestone.
6 in. 6 in. 4 in. 8 in.	These beds occur underneath the present floor of the quarry. They consist of fine grained, crystalline, blue limestone.

This quarry contains two sets of important jointing planes. The major joints strike N. 60° E. and are from ten to fifteen feet apart, while the minor joints strike N. 30° W. and are about thirty feet apart. Near the surface, these joints are open and usually filled with soil.

The stone in this quarry separates readily along the bedding planes and can be broken with plugs and feathers into any desired size. The stone contains no shaly seams and has proven very durable for curbing, sidewalks and crosswalks. The stone fades considerably when exposed to the weather.

The stripping, which consists of soil, is plowed in the fall and the flooding of the creek in the spring washes away about two-thirds of it. The quarry is operated intermittently.

THE SPIECE QUARRY.

This quarry, which is operated by August Spiece, is located one mile north of the city. It has not been worked very extensively. The following is a description of the beds from top to bottom:

10 ft.	Very flinty, gray limestone which cannot be used for buildings.
8 ft.	Bluish gray, fine grained, sub-crystalline, compact limestone. This ledge splits along bedding planes into four two foot beds. The stone has a very uniform color and texture and breaks with a very even fracture. Along the joints the stone has a yellowish color.
12 in. 24 in.	Fine grained, yellow limestone, containing large calcite crystals. The stone has a number of bluish streaks which traverse it irregularly. It has the appearance of being a durable building stone.

Below this occur a two-foot bed of solid blue limestone and from fourteen to eighteen inches of shale. This bed of shale occurs immediately above the beds described as occurring in the Reives quarry. The eight-foot ledge of gray limestone can be worked into almost any grade

of building stone. Thus far the quarry has been worked entirely for local consumption.

PALMYRA.

Two quarries have been opened in this vicinity which belong respectively to Wm. Martin and the city of Palmyra. The stone is essentially the same, consisting of flinty beds of limestone of Burlington age.

THE CITY QUARRY.

This quarry is located near the northeast limits of the city and the stone is quaried entirely for macadam. The following is a description of the beds from top to botom:

2-5 ft.	Red clay and chert stripping.
15 ft.	Buff to gray colored limestone, interstratified with layers of chert.
5 ft.	Gray and buff limestone. A prominent suture joint occurs near the top of this bed.
1 ft. 6 in.	Coarsely crystalline limestone, containing large chert nodules.
4-6 in.	Layer of white chert.
4 ft.	Very coarsely crystalline, fossiliferous limestone. Has a gray color near the bottom but changes to a buff near the surface. Sutures occur in the bed.

The stone from this quarry might be used for most purposes for which Burlington limestone is now being quarried. The stone would make a good quality of quicklime and that from several of the upper beds might be used for foundations and other constructional purposes in which the chert nodules are not a serious detriment. The stone is rather soft for a road metal, but when mixed with flint, in proper proportions, ought to make a very durable pavement. The city owns a crusher and the quarry is only worked when stone is needed for improving the roads.

THE MARTIN QUARRY.

This quarry is located on the south bank of North river, about one and one-half miles north of the city. It was opened thirty to thirty-five years ago and has been worked intermittently ever since. The quarry has a face 200 feet long and 50 feet high. The following is a description of the beds from top to bottom:

10 ft.	Stripping.
25 ft.	Alternate beds of limestone and chert. The limestone has a gray color and is coarsely crystalline. The beds are from six to eighteen inches in thickness.
5 ft. 2 in.	Gray, coarsely crystalline, fossiliferous limestone. Suture joints occur throughout the bed
5 ft.	Coarsely crystalline, light gray limestone. Splits into two beds two feet and three feet in thickness. Chert nodules occur in the bed and along the upper bedding plane. Suture joints are numerous.

The most prominent joints strike N. 50° E., N. 18° E. and N. and S.

The limestone in the upper twenty-five feet is of good quality, but is expensive to obtain owing to the necessity of removing the interstratified chert. The stone in the lower portion of the quarry occurs in heavier beds, which can be split into sizes convenient for handling. This is a very good quality of stone, suitable for most constructional purposes. In the lower bed it contains an occasional chert nodule and therefore must be carefully selected. The suture joints are so abundant that one cannot obtain a face which is free from them, without placing the stone on edge. It is thought that the stone is sufficiently strong to permit of this practice without danger. The flint and limestone spalls have been used for macadam, and when in proper proportions, are well suited for this purpose. Neither the flint nor limestone are desirable for macadam when used alone.

This quarry is worked intermittently chiefly to supply the local market. It has been worked by inexperienced quarrymen and is at present in poor condition, the face being badly shattered and the floor being cumbered with waste.

PARIS.

THE GANNAWAY QUARRY.

This quarry, which is owned by T. B. Gannaway, of Paris, is located north of the city, just north of the middle fork of Salt river. It is situated on a hillside and has a west face eighty feet long. The stone is limestone of Burlington age. The following is a description of the beds from top to bottom:

2-5 ft.	Broken stone and clay stripping.
8 in.	Light gray, coarsely crystalline limestone.
2 ft.	Very coarsely crystalline limestone, containing a small amount of iron oxide. A suture joint occurs six inches from the top of the bed. Chert nodules occur in the upper portion of the bed, being especially abundant near the north end.
2 ft. 8 in.	Light gray, coarsely crystalline, fossiliferous limestone. A small suture joint occurs near the middle of the bed. Contains small nodules of altered pyrites.
8 in.	Gray, medium grained, crystalline limestone, containing small nodules of pyrite and hematite.

The joints are not very prominent and very little attention is paid to them in quarrying. They strike N. 50° E. and N. 25° W. The stone is easily quarried and very little blasting is necessary. Stone which is used for caps, sills or coursing, should be selected in order to avoid that which contains iron sulphide. The stone is very durable and can be used for all ordinary constructional purposes. It would make a very good grade of white lime.

On the north bank of the river there is an old quarry, which was opened ten or fifteen years ago, which is worked from two to six months each year as occasion demands. The stone has the same characteristics as that described above, although the beds are somewhat thicker. The output is all consumed in and about Paris.

PIERCE CITY.

THE PEIRCE CITY BUILDING STONE CO.'S QUARRY.

This quarry, which is owned by L. L. Allen and Dennis Driscoll, is located just south of the city limits. It was opened about ten years ago, chiefly to supply the local demand for building stone. It has an east and west face 500 feet long and 15 feet high. It consists of two beds, an upper of eight feet and a lower of seven feet both of which are typical Burlington limestone. The quarry is covered with a stripping of from two to four feet of clay.

The stone in the upper bed is very coarsely crystalline and fossiliferous and has a light gray color. Suture joints occur from six inches to two feet apart. Near the upper surface, this bed contains a layer of chert nodules.

The stone in the lower bed is very similar to that in the upper. It contains frequent suture joints and occasional chert nodules. A bed of chert occurs in the upper portion of this ledge.

The texture of this stone is medium to fine grained. The fine and coarse particles occur in layers which are not separated by bedding or stratification planes.

The hill, at the base of which this quarry is located, extends about 250 feet south where it is broken by a small valley parallel to the face of the quarry. There is an abundance of limestone in and near the quarry which it is intended to devolp on an extensive scale.

The company is contemplating the erection of a modern mill equipped with machinery for sawing and dressing the stone.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.673
Porosity	1.239 per cent.
Ratio of Absorption	.469
Weight per cubic foot	165. lbs.
Transverse strength	2079.46 lbs. per sq. in.
Crushing strength	11,270. lbs. per sq. in. on bed. 9,325. lbs. per sq. in. on edge.
Crushing Strength of samples subjected to freezing test	9028.7 lbs. per sq. in.

Mill of the Phenix Stone and Lime Company, Phenix, Mo.

Specific Gravity		2.663
Porosity		1.939 per cent.
Ratio of Absorption		.742
Weight per cubic foot		163.2 lbs.
Tranverse Strength		1684.7 lbs. per sq. in.
Tensile Strength		883.5 lbs. per sq. in.
Crushing strength	(a)	11,748.3 lbs. per sq. in. on bed.
		11,366. lbs. per sq. in. on edge.
	(b)	12,375. lbs. per sq. in. on bed.
		12,530. lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	(a)	11,121.5 lbs. per sq. in. on bed.
	(b)	12,146.5 lbs. per sq. in. on bed.

(a) Samples of stone free from suture joints.

(b) Samples of stone containing sutures 1/4" in depth.

The tensile and transverse strength tests were made on pieces which were coarser grained than the ordinary run of stone from the quarry, which accounts for the results not being higher. In the two sets of crushing strength tests which were made there was a loss due to freezing and thawing in the first instance of 626.8 pounds per square inch; and in the second case of 228.1 pounds per square inch. The crushing strengths of the fresh and frozen samples are so near alike as to warrant one in saying that the strength of the stone is very little affected by alternate freezing and thawing. The samples (a) show a crushing strength of 382.3 lbs. per sq. in. more on bed than on edge; while the samples (b) show a crushing strength of 155 lbs. less on bed than on edge. This stone can apparently be used with equal safety on bed or on edge.

ST. LOUIS.

Practically all the common building stone, as well as the limestone used for macadam and concrete in St. Louis, is obtained from the formation known as the St. Louis Limestone. This formation belongs to the Mississippian or Lower Carboniferous. It has an estimated thickness of 250 feet and underlies a large part of the eastern half of St. Louis county, including the city of St. Louis. North and west of the city, it is overlain with beds belonging to the Pennsylvanian or Upper Carboniferous.

The Mississippian series forms precipitous bluffs along the Mississippi river south of the city, and constitute a part of what is known as the St. Louis Carboniferous basin.

In Bulletin No 3, published by the Missouri Geological Survey in 1890, there are several tables of chemical analyses which indicate the variations in the composition of the different beds. These tables have been copied in this report and will be found in Chapter XI. The variations in composition between different beds show that there must have been a considerable difference in the condition at the time the sediments were deposited. The insoluble residue varies from 0.76% to 19.96%; the

The limestone comes to within a foot or two of the surface and is separated into knobs by the weathering along joints and seams which are now filled with clay.

The stone is essentially the same in all parts of the quarry, having the color and texture of typical Burlington limestone. In color, it is not quite as light as that from Carthage, but it is not sufficiently dark to in any way affect its use as a white limestone. The suture joints are not large or deep, although many of them have been opened up through weathering as shown by the natural exposures.

The company has started a second opening across the ravine, southeast of the one now being operated. At the time the quarry was inspected, no stone had been taken out. There is practically an inexhaustible supply on the ridge where this opening is located. Just northwest of the mill the company at one time worked an opening which has not been operated for a number of years and probably will not be reopened.

The stone from the south part of the quarry is used for burning lime. Two continuous kilns are operated and a good grade of white lime is produced. All the waste from the quarry is used in this way, as well as the stone from the bouldery portion at the surface.

The quarry is well equipped with machinery for quarrying, handling and dressing the stone. The mill for sawing the stone is located south of the quarry and is connected with the quarry by a tramway. The mill is equipped with all modern machinery, including engines, pumps, gang-saws and traveling crane. The gang-saws will take blocks 10 feet 6 inches, 8 feet 6 inches and 6 feet 6 inches in length. The stone is sawed parallel to the bed as in the case of that in the Carthage quarries. The quarry is equipped with channelers, steam drills, derricks and other necessary machinery. The company operates its own electric light system by which the plant and the houses of the employees are lighted.

LABORATORY EXAMINATION.

Chemical Analysis.—The following analysis shows the composition of the stone from this quarry:

Insoluble	.21
Fe_2O_3, Al_2O_3	.23
$CaCO_3$	99.06
$MgCO_3$	.58
Total	100.08

This is a remarkably pure limestone, being over 99 per cent. calcium carbonate.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

PHENIX LIMESTONE.
Lawrence County Courthouse, Mt. Vernon, Mo.

THE ALLEN QUARRY.

This quarry, which is owned and operated by J. W. Allen of 4824 Broadway, is located just east of his residence, on the river bluff west of the St. Louis, Iron Mountain and Southern railroad tracks. It has been worked as far as possible to the west and for about 250 feet north and south. The limits of the property will only allow quarrying for about thirty feet more to the south. The following is a section of the quarry from top to bottom:

15-20 ft.	Loess stripping.
20 ft.	Fine grained, gray limestone; thinly bedded. Two layers twelve to fourteen inches in thickness. Makes good pier stone.
1 ft. 6 in.	Finely crystalline, hard, dark blue limestone. Splits into ten and eight inch-layers.
12-14 ft.	Granular, porous, bluish gray limestone, rather soft and works easily.
4 ft.	Massive bed of white limestone.

This quarry is not being operated very extensively. The rock is used mainly for rubble and furnace flux. For the latter purpose, all but the one and one-half foot bed can be used.

THE BEMMEY QUARRY.

This quarry, which is owned and operated by Wm. Bemmey, is located on the hill north of the Emmerick qurray, described on a following page. It is in the St. Louis limestone and consists of a rectangular sunken opening 175 feet by 80 feet. The following is a section from top to bottom:

6-12 ft.	Loess stripping.
10-15 ft.	Sandy, granular, gray limestone. The stone is cross bedded and at the north end there is about six feet of shelly rock. These beds decrease in thickness to six feet at the east end.
3 ft.	Dark gray limestone containing dark spots. Bedding planes are irregular and the stone breaks with an uneven fracture.
2 ft. 6 in.	Limestone similar to the bed above.
10 in.-12 in.	Limestone and dark colored shale.
8 in.	Calcareous blue shale.
1 ft. 4 in.	Fine grained, compact, brittle, dark gray limestone.
10 ft. 6 in.	Fossiliferous, gray limestone, in layers from two to eight inches in thickness. Is finely crystalline and compact.
5 ft. 10 in.	Fine grained, fossiliferous, gray limestone, in beds from two to four inches in thickness. Dark colored flint nodules occur throughout the ledge.
6 ft. 9 in.	Finely crystalline, fossiliferous, dark gray limestone. In layers from two to six inches in thickness. At the west end the uppermost layer has a sandy texture and is twelve inches thick.

The quarry is equipped with a small jaw crusher, a derrick, steam hoist, steam pumps, cars and a movable track. Rubble and crushed stone are the chief products. The quarry was not being worked when

visited in the spring of 1902. This stone was used in building the settling tanks at the water works.

THE BAMBRICK-BATES CONSTRUCTION CO.'S QUARRIES.

Four quarries owned by Mr. Bambrick are at present operated in this city. They are all situated in the St. Louis limestone and so located that stone can be supplied in the north and west parts of the city with a minimum haulage. The office of the company is located at Grand avenue and Forest Park boulevard.

The quarry at Grand avenue and Forest Park boulevard is just east of the Heman Construction Co.'s quarry. It is rectangular in shape and contains practically the same beds as the Heman quarry described on a following page. The stone contains bitumen along some of the short tight seams. Portions of the west face have been colored by the precipitation of iron oxide from chalybeate waters.

The quarry is equipped with a crushing plant, derrick, steam hoists and steam drills. The chief products are rubble and crushed stone.

The quarry operated by this company at the corner of St. Louis and Union avenues is a sunken opening approximately 300 feet by 200 feet in size. Thick deposits of loess, which originally covered this quarry, have been removed by the St. Louis Hydraulic Press Brick Company, for use in the manufacture of brick. The following is a description of the beds from top to bottom:

3 ft.	Decomposed, bouldery limestone.
1-2 ft. 6 in.	Fine grained, yellowish brown limestone having a porous, sandy texture. Contains thin veins of calcite. This bed appears at the southwest corner of the quarry.
4 ft.	Crystalline, gray limestone. Splits into two heavy beds.
19 ft.	Finely crystalline, gray limestone in beds from two to eighteen inches in thickness.
7 ft.	Finely crystalline, dark gray limestone. Very porous near the top. Shows evidence of bitumen.
4 ft. 10 in.	Fine grained, compact, dark gray limestone, containing dark flint nodules. Bituminous material occurs along the jointing planes.
8 ft.	Compact, fossiliferous, gray limestone, in beds from two to four inches in thickness. Beds are separated by very thin layers of shale. Near the middle occurs a ten inch bed of fine grained, siliceous limestone.
2 ft. 10 in.	Medium grained, crystalline, gray limestone. Splits along stratification planes.
7 ft. 6 in.	Dark gray limestone. Splits into two beds the upper of which is a fine grained, impure, bluish gray limestone. The lower bed is a finer grained, crystalline limestone containing fewer impurities.
11 ft. 6 in.	Fine grained, drab limestone. Upper beds are somewhat lighter colored than the lower. Separates into beds from one to two feet in thickness. The stone is brittle and works easily.

The beds have a slight dip to the northeast.

In general, the stone from this quarry is of good quality. It works

well into rubble and crushed stone. The equipment consists of a No. 5 Austin crusher, two pumps, one derrick and a steam hoist. An average of twenty-five men are employed. The street railway companies obtain ballast at this place.

The quarry located at the corner of Angellica and Florissant streets has a somewhat irregular outline, with a total working face of about 325 feet. At the time it was examined, the lower portion was filled with water and other parts were covered with stripping. It is covered with thirty feet of loess. The stone is similar to that at the Perkinson quarry described on a following page. It is a fine grained, crystalline limestone and is used mainly for rubble and crushed for macadam. The major joints strike east and west and north and south. From twelve to fifteen men are employed.

The quarry located at the northeast corner of Clayton Road and Taylor avenue has been operated quite extensively, having been opened about 430 feet east and west and 200 feet north and south. The middle part was covered with water at the time it was examined. The east end was not in very good working condition. When examined in 1902 operations were being carried on entirely at the west end. The following is a section from top to bottom, taken at the northwest corner of the quarry:

20 ft.	Loess and clay stripping.
28 ft.	Finely crystalline, bluish gray limestone in beds from three to fourteen inches in thickness. Ten feet from the bottom, this ledge contains thin layers and nodules of chert.
10 in.	Finely crystalline, bluish gray limestone. Shows a suture joint in the middle. Ledge can be broken into blocks of large dimensions.
4 ft. 3 in.	Soft, yellowish limestone. From six inches to one foot, at the top, is white. Contains nodules of dark flint and pockets of clay. The stone from this ledge is crushed.
11 ft. 10 in.	Crystalline, bluish gray limestone, in beds from four to twelve inches in thickness. The two upper beds are from fourteen to sixteen inches thick.
6 ft. 3 in.	Finely crystalline, bluish gray limestone. In beds from six to ten inches in thickness. Contains thin calcite veins, filling joint planes.
5 ft.	Fine grained, soft, argillaceous, gray limestone. Splits into four beds. Has a buff color along bedding planes. Small suture joints occur in this stone.

The major joints strike N. 40° W., N. 35° E., and N. 80° E. They are open at the top and occur from ten to thirty feet apart.

The stone is hoisted from the quarry in movable wagon boxes, by means of derrick and steam hoist. The quarry is equipped with a crushing plant, steam drills and two pumps. An average of from twenty to tyenty-five men are employed.

The stone is used for building purposes and manufactured into macadam. It has the appearance of being very durable.

THE BUSSEN QUARRY.

This quarry, which is located one and one-half miles south of Jefferson Barracks, is owned and operated by Albert Bussen. It is situated on one of the river bluffs and has an east face 300 feet long and forty feet high. The rock is a finely crystalline, gray limestone belonging to the St. Louis formation. It occurs in beds from three inches to two feet in thickness. Small nodules of chert occur in the lower and upper beds of the quarry, but they are not sufficiently abundant to injure the stone for furnace flux, for which the stone is quarried exclusively.

A second opening is being made on the south side of a small ravine just south of the present quarry. An abandoned opening, about the size of the one now being worked, is located on the north side of the ravine.

THE CRYSTAL SPRINGS QUARRY.

This quarry, which is owned by James F. and Richard Rothwell, is located one-half mile west of Vigus, at the northern edge of St. Louis county. A side track connects the quarry with the St. Louis, Kansas City and Colorado railroad. It is situated on a bluff along the Missouri river and has a face 400 feet long. The following is a section of the quarry from top to bottom:

4 ft. 6 in.	Fine grained, gray limestone in rather heavy beds. Contains short tight seams colored red with iron oxide.
12 ft.	Fine grained, compact, gray limestone. In beds from two to six inches in thickness. Stone is very brittle and contains short tight seams stained with iron oxide.
7 ft.	Finely crystalline, light gray limestone. Works easily.
15 ft.	Finely crystalline, dark gray limestone, in beds mainly from two to six inches in thickness. The twenty inch beds occur near the top.
10 ft.	Finely crystalline, gray limestone. Bedding planes are very uneven. The stone is not uniformly colored, being light and dark colored in spots.
10 ft.	Fine grained, compact, gray limestone. Is brittle and breaks with an irregular fracture. Is crushed and used for rip rap.

The quarry can be worked fifteen feet deeper before pumping will be necessary.

This quarry is equipped with a No. 3 Gates crusher, revolving screen, bucket elevator and a Sullivan steam drill. The stone is carried to the crusher by a cable tramway which is operated by steam. The quarry produces crushed stone and building stone, most of which is shipped by rail to St. Louis. Stone from this quarry was used in the abutments of the Ashley road bridge over the Endland Electric Railway tracks.

THE CAVANAUGH QUARRY.

This quarry, which is owned and operated by T. Cavanaugh, is located southwest of Marcus avenue and Natural Bridge road. It is of the sunken type and is 150 feet long, 100 feet wide and 60 feet deep. Practically the same beds occur here as at the Hill-O'Mera quarry. Those which are being quarried at the bottom are the same as those which are channeled by the Hill-O'Mera company. The stone is a finely crystalline, gray limestone of excellent quality. It breaks well and makes a first class rubble.

The quarry is equipped with a crushing plant, steam hoist, derrick and steam drills. An average of about twelve men are worked. The product is chiefly rubble and crushed stone.

THE EMMERICK QUARRY.

This quarry, which is operated by Phillip Emmerick, is located two miles northeast of Spanish Lake. It was opened in 1878 and has been worked intermittently since that time.

It is situated on a hillside and has a face 800 feet long and 18½ feet in height. The quarry has been worked into the hill a distance of 75 feet. The stone is a bluish gray, compact, fine grained limestone. The upper six feet consists of beds from one to two inches in thickness, while the lower twelve feet is a single massive ledge, which splits readily into blocks of almost any desired thickness. The stone contains occasional dries which have no fixed direction in the quarry. The stripping consists of ten feet of loess.

The stone is used chiefly for buildings and macadam. It has been sold to some extent for rubble work.

EYERMAN BROS. QUARRIES.

Gottlieb and George Eyerman, of Pestalozzi street and Iowa avenue, own and operate two quarries, the stone from which is mainly used in their business as contractors.

The quarry near Maeder street and Virginia avenue is a large, rectangular, sunken pit which has been opened 350 feet east and west and 175 feet north and south. The following is a section of the quarry from top to bottom:

20-30 ft.	Clay and loess stripping.
8 ft.	Crystalline, gray limestone. Consists of three beds 2 feet 8 inches, 3 feet, and 2 feet 4 inches in thickness. The uppermost bed is decomposed and shelly.
7 ft.	Medium grained, arenaceous, gray limestone, showing cross-bedding throughout the quarry. This stone is difficult to work.
9 in.	Finely crystalline, compact, gray limestone.

3 ft.	6 in.	Rough, spotted, bluish gray limestone. Difficult to work.
1 ft.	6 in.-2 ft. 6 in.	Grayish colored limestone, with dark spots. Contains considerable calcite and pyrite. Upper surface is rough. Stone is of inferior quality.
3 ft.	6 in.	Fine grained, mottled, gray limestone. The lower eight inches contains seams of bluish shale.
6 ft.	6 in.	Fossiliferous, gray limestone. At the south side of the quarry it splits into four or five thick beds. In other parts of the quarry it splits into thinner beds.
17 ft.		Fine grained, compact, fossiliferous, white limestone, in beds from one to four inches in thickness. Two feet from the top, about three feet of this ledge contains abundant small, black chert nodules. Fine veins of calcite are of common occurrence.
4 ft.		Fine grained, compact, white limestone. Tight sutures occur about six inches apart. In the upper part of the ledge there are small nodules and a two inch layer of black flint.
3 ft.	10 in.	Gray, arenaceous limestone having a somewhat oölitic appearance, exhibits cross-bedding and small suture joints.
1 ft.		Compact, crystalline, gray limestone.
	10 in.	Two five inch beds of fine grained, compact, gray limestone, containing thin veins of calcite.
2 ft.	3 in.	Similar to the above bed. Splits into three beds of eight inches, fifteen inches and four inches.
	7 in.	Finely crystalline, gray limestone. This stone is used mainly for sewer caps.
	22 in.	Similar to the bed above. Caps along bedding plane two inches from top.
2 ft.		Medium grained, crystalline gray limestone. Splits into beds from two to six inches in thickness.

This quarry is in the St. Louis limestone and most of the stone has a fine grained, compact texture, which is evidence of its durability. The output is mainly rubble. Some of the stone is broken by hand for macadam. Sewer intakes are constructed out of the stone from one ledge in the quarry.

The beds dip slightly to the west, affording a natural drainage in this direction. The water is pumped from the quarry and discharged into the city sewer.

The stone is hauled by team, up an inclined roadway at the north side of the quarry. From six to eight men are employed at this place. The only machinery used is one steam drill.

The quarry at Grand avenue and Hickory streets has been opened for a distance of 250 feet north and south extending between Car lane on the east and Grand avenue on the west. The beds in this quarry dip northeast, in which direction the water is drained. The following is a section from top to bottom:

10-15 ft.		Clay and loess stripping.
24 ft.		Compact, gray limestone, in beds from six inches to three feet in thickness.
7 ft.	6 in.	Granular, gray limestone. Splits near the middle into two beds. This ledge is thinner on the east and north sides of the quarry.

2 ft.	7 in.	Finely crystalline, gray limestone. Contains thin veins of calcite.
7 ft.	6 in.	Medium to fine grained, gray limestone. Splits in the middle into two beds.
2 ft.	2 in.	Medium to fine grained, gray limestone. Caps six inches from the top. At the east end of the quarry, this bed is about twelve inches thick.
	2 in.	Dark shale.
4 ft.		Dark colored limestone, having an irregular bed of blue shale one foot from the bottom.
3 ft.	6 in.	Fine grained, compact, gray limestone. Containing an occasional thin vein of calcite.
3 ft.		Argillaceous, yellow limestone. Very soft.
7 ft.		Fine grained, drab limestone. Splits along a suture joint one foot from the top, and also along a bedding plane six inches below this. A layer of flint occurs three feet from the top. Along the jointing planes the stone has a yellowish color. Can be worked easily with plug and feathers and breaks with an even fracture. The stone is somewhat argillaceous and contains occasional thin seams of dark colored calcite.
7 ft.		Consists of eighteen inches of dark gray, flinty limestone; twenty inches of limestone having thin shaly seams; fifteen inches of dark gray limestone; and thirty inches of dark, bluish colored limestone, containing nodules of flint in the upper part. The stone from this horizon is only used for crushing.
6 ft.		Fine grained, compact, gray limestone. Contains a number of bedding planes, the principal one being two feet from the bottom. The beds are distinctly ripple marked. The upper one foot is shelly and shows dark stratification planes. The stone is soft and argillaceous and has been altered to a yellowish color along the joints.
3 ft.	9 in.	Soft, argillaceous, medium grained, gray limestone. A layer of chert occurs two feet from the top. Stone is rather soft for rubble.
3 ft.	6 in.	Finely crystalline, compact, gray limestone. Somewhat difficult to work.

In general, the lower beds of this quarry are argillaceous and soft. The stone cannot be quarried during freezing weather, owing to the danger of disintegration. After the stone is seasoned, it takes on a lighter color than when first quarried. The major joints strike N. 25-30° E.

The quarry is equipped with a derrick, steam hoist, steam drill, pumps and crushing plant. The stone is hoisted in movable wagon boxes, as is the practice at many of the sunken quarries in St. Louis.

THE FINK QUARRY.

The quarry owned and operated by Mr. George T. Fink is located west of the Hanley road and north of Edon post office. When visited it had not been in operation for some time and was partly filled with water. The quarry has a stripping of from ten to twenty feet of loess. The rock is a very fine grained, fossiliferous, thinly bedded limestone.

THE FRUIN BAMBRICK CONSTRUCTION CO.'S QUARRIES.

The quarries owned and operated by this company are among the largest in the St. Louis district. This company does an extensive general and railroad contracting business and has offices in the Chemical building. William H. Swift, who is the principal owner, has been president of the company since its organization. This company owns and operates three quarries, all of which are located near Chouteau and Spring avenues, west of Grand avenue. The largest of these quarries is located at the northeast corner of Chouteau and Grand avenues and covers nearly a block of ground. The second quarry, which is west of Spring avenue and near the north end of the large quarry, is considerably smaller. The third quarry, which is on the south side of Chouteau avenue and east of of the main quarry, contains some of the best stone on the property. This quarry is not in operation.

The first quarry, which has been operated for twelve years, covers an area of six acres. The beds dip in all directions from the center, although the east and south dips are the most pronounced. The following is a section from top to bottom:

6-18 in.	Dark gray, medium grained limestone.
18 in.	Crystalline, white limestone. Dresses nicely and is a very good stone.
6 ft.	Argillaceous, yellow limestone. Portions of this ledge contain workable stone.
18 in.	Bluish gray limestone. Beds are separated by a thin layer of shale.
18 in.	Used for furnace flux.
7 ft.	Limestone known as the "nigger head" ledge. Very difficult to work.
10 in.	Fine grained limestone.
3 ft.	Somewhat siliceous, white limestone.
16 ft.	Consists of three ledges of rather fine grained, bluish gray limestone.
3 ft.	Flinty, bluish gray limestone, in thin layers.

In general, the stone is rather soft. It is used for buildings, concrete and macadam. The equipment consists of two crushing plants, operating No. 3 and No. 4 Gates crushers, derrick, steam hoists and steam drills. The crushed stone is stored in bins. The quarry west of Spring avenue is operated most extensively, the stone being crushed at the larger quarry. The following sizes are made:

(1) Fine screenings, consisting of particles about the size of wheat grains. Is used in concrete for cellars and sidewalks.

(2) Screenings, consisting of particles about the size of shelled corn. Used for the bed of granitoid sidewalks.

(3) Macadam (A)—1 inch used in light concrete work.
(B)—1½ inch used in heavy concrete work.
(C)—2½ inch used in macadam.

"Flour," which is very finely pulverized limestone, is also made at this quarry. It is used as a wall finish and in asphalt work. The fine screenings are used for manufacturing this product. They are dried and ground in a ball mill four feet in diameter and eighteen feet long. This mill consists of a cylinder, lined with very hard rock and containing a quantity of round flint pebbles. The abrading action of the flint pebbles on the screenings, as the cylinder is revolved, reduces the screenings to an impalpable powder, which is sacked and sold as it comes from the cylinder.

This quarry is operated about ten months in the year and employs about one hundred men. The output is about ninety loads of macadam and ten loads of building stone per day.

THE FEHLIG CONSTRUCTION CO.'S QUARRY.

This quarry is located near the intersection of Hickory street and Car lane. The same strata are quarried as at the Grand avenue quarry of Eyerman Bros. The quarry consists of a deep rectangular pit, having perpendicular walls. The company recently erected a large crushing plant and have materially increased their output.

Mr. Frank Fehlig is president and treasurer of the company and Mr. T. L. Fehlig is secretary. The offices are located at the corner of Theresa avenue and Hickory street.

THE FRIEDRICK QUARRY.

This quarry, which is owned and operated by Jacob Friedrick, is located at the junction of Minnesota avenue and Maeder street. It covers an area about 325x135 feet. The upper thirty feet consists of thinly bedded white limestone, which is used by the mills in St. Louis for whiting. When ground, the stone from these beds is very white. It brings $1.25 per ton delivered at the mills. From one of the lower ledges, stone is quarried for sewer intakes. The general section of this quarry is the same as that of the Kempf and Hoge quarry, located on adjacent property.

The major joints strike N. 10° E. Apparently they do not extend to any great depth. The beds have an apparent gentle dip to the northwest.

The quarry is equipped with a hoist and derrick. Six men and three teams are worked.

THE GEISEL CONSTRUCTION CO.'S QUARRY.

This quarry, which is located just north of the Hoffman quarry, described on a following page, was opened in 1891 and operated until 1900. It extends along the bluff 150 feet. The same beds are worked as at the Hoffman quarry, and also the following which occur underneath:

6 ft.	Heavy bed of yellowish limestone.
10 ft.	Gray limestone.
8 ft.	Gray, fine grained limestone, in beds from four to ten inches in thickness.

The beds have an apparent dip of 20° to the west. The quarry is not being operated at present.

THE HILL-O'MERA CONSTRUCTION CO.'S QUARRY.

This quarry, which is owned and operated by J. B. O'Mera and John Hill, under the firm name of the Hill-O'Mera Construction Co., is one of the best equipped in the city. The quarry, which is located at the corner of Ashland and Euclid avenues, is a deep, sunken opening having a rather irregular, circular outline, about 400 feet in diameter. It has been in operation since 1876, and a large quantity of stone has been quarried. The following is a description of the beds from top to bottom:

15-18 ft.	Loess stripping.
15-20 ft.	Fine grained, gray limestone. Thinly bedded. These beds are broken into boulders at the west end.
7 ft.	Finely crystalline, gray limestone. Thinly bedded. Flint nodules occur in the lowest bed.
3 ft. 8 in.	Dark colored limestone. A bed of dark colored chert nodules occurs one foot from top. The stone is porous and soft and contains calcite geodes and pockets filled with soil.
5 ft. 6 in.	Finely crystalline, fossiliferous, gray limestone. Splits into four or more beds. Contains short tight seams.
7 ft. 6 in.	Fine grained, compact, gray limestone in beds from two to six inches in thickness.
9 ft.	Fine grained, dark gray limestone. Splits into beds from six to ten inches in thickness.
2 ft. 8 in.	Porous, soft, dark colored limestone.
4 ft. 4 in.	Finely crystalline, gray limestone. A dark suture occurs fourteen inches from the top. Small dark flint nodules are scattered throughout the bed. The upper foot of the ledge is darker than that below.
4 ft.	Fine grained, compact, gray limestone. Contains a thin bed of black flint one foot from the top, and small, black flint nodules throughout the mass.
5 ft. 2 in.	Finely crystalline, compact, dark gray limestone, in thin beds from four to six inches in thickness. Upper portion contains small, black chert nodules.
7 ft.	This ledge consists of two beds of finely crystalline, gray limestone which saws and dresses nicely. With the exception of the lower two and one-half feet the stone contains dark stratification planes. The upper six inches is not cut or dressed. The stone is quarried with a channeling-machine.

4 ft.		Consists of limestone, having a somewhat finer grain than the bed above. Dark stratification planes occur near the base. The stone is very light colored when dressed. This ledge is worked with a channeling-machine.
4 ft.		Fine grained, gray limestone.
1 ft.	8 in.	Stone similar to bed above.
1 ft.	0 in.	Compact, very fine grained, dark gray limestone in beds from six to ten inches in thickness. Contains dark flint nodules.
4 ft.	4 in.	Fine grained, brittle, dark gray limestone, in beds from six to ten inches in thickness.
	3 in.	Blue shale.
3 ft.	4 in.	Fine grained, compact, gray limestone.
5 ft.	6 in.	Stone similar to bed above.
1 ft.	4 in.	Shelly limestone.
4 ft.	2 in.	Finely crystalline, dark gray limestone. Breaks with an irregular fracture.

The beds have an apparent dip to the northeast. The best stone in the quarry occurs in the two ledges which are channeled. That from the remaining beds is used for rubble and crushed stone. The stone, which is channeled, has a very pleasing white color and is very durable, when free from stratification planes. Owing to the presence of these planes, the stone should not be laid on edge, if one desires the greatest strength.

With the exception of the Stolle Stone Co., this is the only company in St. Louis which uses channeling machines, in quarrying, and gang-saws in cutting the St. Louis limestone. The quarry is equipped with a channeler, a crushing plant, a pumping outfit, steam drills, steam hoist and derricks. The stone saws with about the same rapidity as the Carthage limestone, viz., at the rate of two inches per hour. That which is channeled is used chiefly for caps, sills and coursing. About thirty men are employed in the quarry.

THE HEMAN CONSTRUCTION CO.'S QUARRIES.

This company operates two quarries, located respectively at Spring avenue and Forest Park boulevard and at Ashland and Marcus avenues. The company is incorporated and consists of August and J. C. Heman. Both quarries are in the St. Louis limestone and the product of each is chiefly crushed stone and rubble.

The quarry located at the northeast corner of Spring avenue and Forest Park boulevard has been opened about ten years, and is about 250 feet by 150 feet square. It is a sunken quarry and the following is a section from top to bottom. The stripping of loess has been removed for the manufacture of brick.

10 ft.	Crystalline, gray limestone in beds from six inches to two feet in thickness.
2 ft.	Decomposed, yellowish limestone. Chiefly waste.
1 ft.	Crystalline, yellow limestone.
3 ft.	Compact, crystalline, dark gray limestone.
2 ft.	Stone similar to bed above.

3 ft.	9 in. Medium grained, gray limestone containing scattered chert nodules. Splits along bedding planes six and twelve inches from top.
6 ft.	6 in. Very fine grained, compact, dark gray limestone, in beds from six to ten inches in thickness.
2 ft.	3 in. Yellowish gray limestone, containing calcite geodes. At the west end of the quarry, this bed contains pockets filled with soil.
10 in.-14 in.	Fine grained, soft, dark gray limestone.
3 ft.	10 in. Finely crystalline, gray limestone. Splits into beds of various thicknesses, in different parts of the quarry.
	9 in. Dark gray limestone. Two inch layer of shale occurs between this and the ledge below.
2 ft.	7 in. Fine grained, gray limestone. In the west part of the quarry, the ledge splits into several beds.
6 ft.	10 in. Argillaceous, fine grained heavily bedded magnesian limestone. The fresh stone has a light gray color. Will split into beds of almost any desired thickness.
4 ft.	Drab limestone. Stone in lower part of this bed is more finely crystalline than that above. Contains short dry seams and joints which carry bitumen.
3 ft.	3 in. Fine grained, gray limestone. This ledge splits into beds of different thicknesses, depending upon their position in the quarry. The stone breaks with an irregular fracture.
5 ft.	9 in. Finely crystalline, dark gray limestone. In some parts of the quarry eighteen inches can be capped from the upper portion of this bed. Two small suture joints were observed near the middle of the ledge. The stone exhibits a white efflorescence after being weathered for some time in the quarry.

This quarry produces chiefly rubble and crushed stone. It is equipped with a No. 3 Austin crusher and accessories. The crushed stone is separated into screenings one and one-half and two and one-half inch sizes. About twenty men are employed.

The quarry which is located between Ashland and Loraine avenues, west of Marcus avenue, is located just west of the Mound City Construction Co.'s quarry. In 1902 a complete crushing plant was being installed, and it is expected to operate the quarry more extensively than it has been at any time in the past.

This quarry has a vertical face of about sixty feet and the stone is essentially of the same quality as that in the quarry of the Hill-O'Mera Construction Co. Owing to a gentle northeast dip to the strata, the lower beds worked at the Hill-O'Mera quarry have not been reached. The quarry contains some very good stone. The lower portion of the face could not be examined on account of water which had accumulated since the opening was last operated.

THE HOFFMAN QUARRY.

This quarry, which is owned and operated by Fred Hoffmann, is located on the river bluff at 2718 Wyandotte street. It was opened in 1891 and has a working face of about 150 feet. The following is a section from top to bottom:

0-15 ft.	Stripping.
1 ft. 6 in.-5 ft.	Gray limestone, having a sandy texture.
10 ft.	Flinty, gray limestone, usually crushed for macadam.
5 ft.	White limestone, in beds from four to five inches in thickness. This is known as the "glass ledge," on account of the brittle character of the stone. Thin veins of calcite occur in these beds.
3 ft.	Dark gray limestone, containing some flint and occasional calcite nodules. From one to fourteen inches of the upper portion of this ledge has a brown color.
3 ft. 10 in.	A twenty-eight inch and an eighteen inch bed of finely crystalline, white limestone, used for footing and dimensional purposes.
5 ft.	Crystalline, gray limestone in thin layers. Used for rubble and footing.

The beds in this quarry have a dip of 15° W. When operated, this quarry employs from two to three men.

THE HALLER BROS. QUARRY.

This quarry, which is owned and operated by Haller Bros., is located just south of the Knaus quarry, near Minnesota and Delor avenues. It was opened six years ago, and has been worked 250 feet north and south and 100 feet east and west. The stone consists of thin beds of compact, white limestone similar to those near the top of the Eyerman quarry on Maeder street. The beds are mainly from two to six inches in thickness. The upper portion of the quarry has a three-foot horizon which contains black chert nodules. The major joints strike N. 20° E. The beds have an apparent gentle dip to the south.

Three or four men are employed at the quarry, the stone being used by the company chiefly in contract work. Some of the stone is broken by hand for macadam. The company expects to install a derrick and hoist to facilitate handling the stone, which is now hauled up an inclined roadway at the west end of the quarry.

THE KEMPF QUARRY.

This quarry, which is located two miles north of Barretts Station, on the Missouri Pacific railroad, was opened by John Reige in 1875 and has been worked intermittently ever since. It is situated on the west side of the bluff and has a working face of about 150 feet.

The rock is limestone and occurs in two ledges of ten feet each. The stone in the lower ledge is very fossiliferous and varies in color from yellowish buff to gray, depending upon its position with reference to the bedding and jointing planes. It has a granular matrix, in which are imbedded large and small crystals of calcite. It can be split into beds about two feet in thickness.

The upper ledge varies in thickness from six to ten feet. The stone has a yellowish or buff color and is somewhat softer than that in the lower bed. It can be split into beds of almost any thickness. The

quarry is covered with one foot of broken chert nodules and three feet of red clay. The major joints strike N. 70° E., N. 50° E. and N. 30° E. The quarry is worked entirely by hand and the stone is used chiefly in buildings, bridge abutments and macadam pavements.

THE KNAUS QUARRY.

This quarry, which is operated by Mr. Joseph Knaus of 4337 California avenue, is located at the intersection of Minnesota avenue and Delor street. It is a large, rectangular, sunken pit 250 feet by 200 feet. It is bounded on three sides by city streets, and must be quarried out of the bottom. The quarry now has a 55-foot vertical face, covered with from two to twenty-five feet of loess stripping. The bottom of the quarry is in the "sewer intake ledge," and the same stone is obtained as at the Eyerman quarry. The upper sandy ledge is not as distinctly cross bedded as in the Eyerman quarry. At the east end, the stone above this bed has been removed by erosion. At the west end, about ten feet of heavily bedded limestone occurs above the sandy ledge. The beds have an apparent gentle dip to the west. Considerable water enters the quarry, but it is carried away by a natural underground outlet at the northwest corner. The water is pumped from the west side into this drain.

The major joints strike north and south, and apparently do not extend to a depth of more than forty feet from the surface. A fault occurs at the east end, having a downthrow of about fifteen feet to the west. This fault zone is about eight feet wide and consists of limestone boulders, cemented together with calcite.

From three to five men are employed at this quarry. The stone is hauled up an inclined roadway at the east end. Rubble and foundation stone are the chief products. In the past some of the stone has been broken by hand for macadam.

THE KEMPF AND HOGE QUARRY.

This quarry, which is owned and operated by Conrad Kempf and John Hoge, is located on Pennsylvania avenue and Maeder street, and joins the Friedrick quarry on the east.

It consists of a large sunken pit which is being worked mainly along the south side. The following is a section of the quarry from top to bottom:

20-25 ft.	Loess stripping.
22 ft.	Fine grained, compact, light gray limestone in beds from two to six inches in thickness.
6 ft.	Finely crystalline, gray limestone. Contains tight sutures from two to ten inches apart. Small nodules of flint occur in the upper part of the bed. It is badly decomposed along the eastern side of the quarry, where it has a brown color. It contains pockets of clay and soil and where these occur the stone is chiefly waste.

3 ft.	6 in.	Consists of three beds of limestone. One has an arenaceous texture, another is very brittle and is known as the "glass ledge," and the third is a gray limestone which works well into ashler blocks.
1 ft.	6 in.	Compact, gray limestone, used mainly for piers.
	7 in.	Crystalline, gray limestone, used for sewer intakes.
1 ft.	4 in.	Gray limestone, used for piers.
7 ft.	6 in.	Finely crystalline, gray limestone in beds from two to six inches in thickness. Thin seams of shale occur between the beds.
10 ft.		Soft, yellowish gray limestone in beds from four to eight inches in thickness.

The lower ten feet is soft and partly decomposed, on account of which it is not quarried at the present time. The stone in the upper part of the face is very durable. The thin white beds have been used in the manufacture of limestone flour. The quarry is supplied with natural drainage. The stone is hoisted in movable wagon boxes by means of a derrick and steam hoist. Five men are employed in the quarry.

THE LAMB QUARRY.

This quarry, which is owned and operated by Nicholas Lamb, is located on 66th street, directly north of Delmar Garden. It is a rectangular sunken pit about 200 feet by 125 feet. It is ninety feet deep and has from ten to thirty feet of loess stripping.

The stone is taken out in ledges from four to six feet thick. It is the usual dark gray, crystalline limestone of the St. Louis formation, and is used chiefly for buildings and street construction.

The quarry is equipped with a No. 3 Gates crusher and accessories, three derricks and a steam hoist. The crushed stone is separated into three sizes, two and one-half inch, one and one-half inch and screenings.

THE LOHRUM QUARRY.

This quarry, which is owned by John C. Lohrum and operated by John A. Lohrum, is located at the foot of Osage street. It is situated on the bluff just west of the Iron Mountain railroad. The following is a description of the beds from top to bottom:

10 ft.		Decomposed, gray limestone.
5 ft.		Compact, white limestone in beds from six to twelve inches in thickness. This and the ledge above do not occur at the south end of the quarry.
7 ft.		Blue limestone. Splits two feet from the bottom, along a thin bed of flint. Building stone is obtained from this ledge.
4 ft.		Flinty, gray limestone. Used for crushing.
2 ft.	6 in.	Solid bed of limestone, used for building.
5 ft.		Compact, gray limestone, used for building.
	6 in.	Fine grained, bluish limestone.
4 ft.		Finely crystalline, blue limestone. Consists of a two foot bed and four six inch beds.
3 ft.		Flinty, white limestone, used for crushing.
12 ft.		Thinly bedded, shelly, gray limestone, used for crushing.

1.

2.

ST. LOUIS LIMESTONE.

Fig. 1. Eyerman Bros. quarry, illustrating typical sunken quarry.
Fig. 2. J. A. Lohrum quarry, illustrating typical bluff quarry.

This quarry is covered with very heavy stripping, which is increasing as the work is extended to the west. Most of the stone is now crushed for macadam, although a number of the beds make very good rubble.

The quarry is equipped with a No. 4 crusher and accessories, a steam drill, engine and boiler. Four sizes of crushed stone are manufactured, three inch, one and one-half inch, screenings and dust. The dust is used in the construction of asphalt pavements. Considerable of the crushed stone has been shipped to Arkansas.

THE MERAMEC HIGHLAND CO.'S QUARRY.

This quarry, which is located about one-fourth of a mile east of Meramec Station on the St. Louis and San Francisco railroad, is one of the best equipped of any of the St. Louis quarries.

The stone in the upper portion of the face is very flinty and can only be used for rough rubble and crushing. The heavy beds in the lower portion of the quarry were at one time channeled into large mill blocks. The stone is very fossiliferous.

The quarry has not been operated for a number of years, but was formerly equipped with channelers, steam drills, crushing plant and gang-saws. The stone was carried from the quarry to the mill by means of an overhead cable, a distance of 1,000 feet. The quarry is connected with the St. Louis and San Francisco railroad by a side track.

THE MOSS QUARRY.

This quarry, which is owned by E. R. Moss and operated by J. L. Moss, is located one-eighth of a mile north of the old Manchester road north of Maddenville.

It consists of a rectangular sunken pit 210 feet by 100 feet. It has a face of 35 to 40 feet, one-third of which is loess stripping. The rock is a fine grained, gray limestone, which splits into beds from three to four inches in thickness. The beds are somewhat thicker at the bottom than at the top of the quarry. The major joints strike N. 20° W.

This quarry is not being operated at present. It was formerly worked by hand, the output being used for buildings and street paving.

THE MADDEN QUARRY.

This quarry, which is owned and operated by Thomas Madden of Maddenville, is located just south of the old Manchester road east of Maddenville.

The quarry has a working face of about 225 feet and has been worked into the hill 100 feet. At the time it was examined, it contained some water. The following is a description of the beds from the top to the surface of the water:

15 ft.		Loess. Stripping.
6 ft.		Fossiliferous, light gray limestone, in beds from three to four inches in thickness.
2 ft.	6 in.	Crystalline, dark colored limestone, containing flint near the top. Small calcite veins and geodes occur in the bed. The weathered surface has a sandy appearance.
1 ft.	6 in.	Fossiliferous, gray limestone, in thin beds.
2 ft.	2 in.	Heavy bed of very fossiliferous, gray limestone.
2 ft.	4 in.	Finely crystalline, compact, fossiliferous, gray limestone.
8 ft.	6 in.	Finely crystalline, fossiliferous, light gray limestone, in beds from two to six inches in thickness.
5 ft.	3 in.	Fine grained, gray limestone. Splits into beds twelve inches in thickness. Upper two feet contains calcite geodes.
5 ft.	5 in.	Granular, dark gray limestone in beds from six to twelve inches in thickness

The quarry is equipped with a crusher and accessories. The products are mainly building and crushed stone. The latter has been used quite extensively in macadamizing the country roads and as ballast on the Suburban Electric road.

Mr. Madden owns another quarry on the west side of the bluffs, just south of the old Nelson Winters' quarry, south of Maddenville. It consists of an irregular opening, about 75 feet square and 20 feet deep. Most of the stone is thinly bedded limestone and of very inferior quality. The upper six feet of limestone has a sandy texture and exhibits strong cross bedding. The thin beds of stone are very brittle and are broken badly when blasted. This quarry has been leased, temporarily, to I. L. Moss, who is getting out rip rap. Three men are employed.

THE MOUND CITY CONSTRUCTION CO.'S QUARRY.

This quarry, which is located on Ashland avenue west of Marcus avenue, was opened in 1898. It consists of a rectangular, sunken pit 250 feet by 150 feet. The stone is essentially the same as at the Heman quarry, described on a preceding page. The quarry has a covering of thirty feet of loess.

The equipment consists of a Gates crusher and accessories, steam drills and a cable hoist., The cable extends the entire length of the quarry and stone from any part may be moved by it. The quarry was not in operation when visited. The output has been mainly rubble and crushed stone.

THE PERKINSON BROS. QUARRIES.

Three quarries, located in the northeastern part of St. Louis, are operated by this company, which is composed of J. E., R. A. and W. H. Perkinson.

These quarries are large rectangular sunken pits, which have been worked to a considerable depth. The stone varies somewhat in texture,

color and in the thickness of the beds in the different quarries and even in the same quarry. In general, however, the stone is the same in all. The output is entirely building and broken stone.

The quarry at Grand avenue and Florissant street consists of a large rectangular opening, about 150 feet square. At present it is being operated on the south side, where the stone is most easily accessible. The following is a section of the quarry from top to bottom as given by Mr. Perkinson:

15-25 ft.		Loess stripping.
4 ft.		Heavy bed of white limestone.
2 ft.	6 in.	Bed of gray limestone, having a sandy texture. The lower fourteen to eighteen inches is somewhat spotted in color. Similar to the bed immediately below.
3 ft.	4 in.	Bed of fine grained, spotted dark and light gray limestone. It has a mottled appearance and on account of the difficulty with which it is worked it is known as the "nigger ledge." Splits near the middle along an irregular bedding plane.
4 ft.		Compact, gray limestone. Splits near the middle. Contains thin calcite seams.
	14 in.	Fine grained, gray limestone. Brittle and spalls with a sharp fracture.
3 ft.	6 in.	Compact, light gray limestone. Suture joints occur about twelve inches apart. Thin veins of calcite occur near the middle of the ledge. This stone is used mainly for piers.
20 ft.		Very fine grained, fossiliferous, white limestone in thin beds from two to eight inches in thickness. Nodules of black flint occur near the top of the ledge. Otherwise the stone is a good building material.
7-8 ft.		Fine grained, crystalline, yellowish gray limestone. Splits into thin beds. A suture joint occurs near the middle.
8 ft.		Finely crystalline, gray limestone. The lower beds are heavy, while those above are thin.
14 ft.		Fine grained, dark gray limestone, in beds from six to twelve inches in thickness. Lower three feet is dark limestone, containing small geodes. This stone is soft when quarried, but toughens by seasoning.
3 ft.		Hard, white limestone. A good building stone.
4 ft.	6 in.	Compact, gray limestone, containing nodules of blue flint. Used mainly for crushed stone.
4 ft.		Fine grained, white limestone. Contains some flint.
	8 in.	Dark gray limestone. Has been used for sewer inlets and dimension stone.
3 ft.	6 in.	Light gray limestone, in thin beds from two to six inches in thickness. Good rubble.
8 ft.		Upper four and one-half feet is white limestone, while the lower three and one-half feet is a soft blue limestone. The upper portion is used for dimension stone and the lower for crushed stone.
3 ft.		Gray limestone, in beds from four to ten inches in thickness. Very good rubble.
4 ft.	6 in.	6 ft. Very hard, dense limestone. In places the stone has a slight reddish tint. It has been used for manufacturing paving blocks.
6 ft.		Gray limestone, having a slight reddish tint. Occurs in beds from six to eight inches in thickness. Used for rubble stone.
2 ft.	6 in.	Dark limestone, having an irregular fracture.
6 ft.		Light gray limestone, used for rough rubble.

This quarry is equipped with steam drills, derricks and steam hoist. All the stone is hoisted in movable wagon boxes. The output is chiefly building stone and rough rubble. Ten men are employed in the quarry.

The quarry located at the southwest corner of Broadway and Bissell street consists of a sunken pit 400 feet by 200 feet, with a maximum depth of 125 feet. A general section of this quarry would show the same beds as occur in the quarry on Grand avenue.

It is equipped with a Gates crusher No. 3, a 20-horse power engine and a 40-horse power boiler. Derrick and steam hoists are used in moving the stone.

The quarry at the southwest corner of Blair and Penrose streets has only recently been worked by Perkinson Bros. and was not in operation when visited. It was formerly opened along Penrose street between 20th and Blair streets. The deep portion consists of a rectangular pit about 200 feet square.

The quarry has a stripping of from 25 to 30 feet of loess. The rock is very similar to that in the other quarries. The equipment consists of a No. 3 Gates crusher with accessories, a 25-horse power engine, 80-horse power boiler, steam hoist and derricks.

THE PEPPER QUARRY.

This quarry, which is operated by Mr. Pepper, is located south of Potomac street along the Mississippi river bluffs. The quarry face consists of about ten feet of gray limestone. The lowest bed, which is three feet ten inches thick, is a medium grained, argillaceous, yellowish gray limestone. A few small suture joints occur in this ledge. The stone above this has a gray color and is more thinly bedded. The stripping consists of twenty feet of loess. The product is chiefly rubble. It is worked intermittently.

THE RUECKING & CO.'S QUARRY.

This quarry, which is located at the intersection of Gasconade and Marine streets, just west of the St. Louis, Iron Mountain and Southern railroad tracks, consists of a triangular sunken pit 300 feet by 200 feet The beds have an apparent gentle dip to the northeast. The stripping of loess, which at one time was very heavy, has been removed for the manufacture of brick. The following is a section of the quarry from top to bottom:

15-20 ft.	Light and dark gray limestone, containing occasional flint nodules, especially in the lower part.
5-6 ft.	Heavy bed of medium grained, yellowish gray, fossiliferous limestone. This stone contains small specks of iron oxide and contains suture joints. It has a granular texture and has the appearance of being almost oölitic.

11 ft.	Finely crystalline, light gray limestone having a sandy texture. A bed of flint occurs two feet six inches from the top. The stone is slightly cross bedded.
6 ft.	Medium grained, fossiliferous, crystalline, gray limestone. Splits along a beding plane two feet from the top.
5 ft. 9 in.	A heavy bed of coarse grained, very fossiliferous, drab limestone.
5 ft. 8 in.	Coarse to fine grained, oölitic, bluish colored limestone. From four to six inches of the stone on either side of the bedding and jointing planes has been altered to a buff color. Crossbedding is exhibited in some parts of the quarry.
6 ft. 10 in.	Very fossiliferous, coarsely, crystalline, bluish colored limestone.

The bed which immediately underlies the quarry face at the northeast corner is somewhat finer grained than that which is now exposed. The upper part of this section does not appear at the east end of the quarry. The stone is being quarried mainly from the lower beds.

The equipment consists of a No. 3 Gates crusher with accessories, a steam hoist, engine, boiler and steam drills. Crushed stone has been shipped from this quarry into Louisiana and Texas.

THE RUPRECHT QUARRY.

The quarry owned and operated by John Ruprecht is located on the St. Louis, Iron Mountain and Southern railroad, one and a half miles south of Jefferson Barracks Station. This quarry produces furnace flux exclusively, which is shipped to St. Louis.

The opening which is now being worked has an east face of about 100 feet. The stripping is very light. The following is a section of the quarry from top to bottom:

4 ft.	Fine grained, drab limestone, in beds from twelve to eighteen inches in thickness.
18 ft.	Thinly bedded bluish gray limestone.
20 ft.	Fine grained limestone, in beds from six to ten inches in thickness.
2 ft. 2 in.	Crystalline, gray limestone.
4 ft.	Fine grained, gray limestone. Very flinty.
10 ft.	Fine grained, gray limestone, in beds from eight to twelve inches in thickness.

The major joints strike N. 45° E., N. 55° E. and N. 20-25° W.

The quarry is equipped with a steam drill and the stone is broken by blasting and sledging. All of the stone is used for furnace flux. The waste is dumped into the Mississippi river.

Formerly Mr. Ruprecht operated a quarry directly south of the present opening. It was abandoned on account of the poor quality of the stone for furnace flux.

THE STIFEL QUARRIES.

Mr. Phillip Stifel owns and operates two quarries located respectively at the corner of Barton and 2nd streets and north of the Natural

Bridge road at Marcus avenue. The office of the company is located at the first mentioned quarry.

The Barton street quarry was opened in 1863 and at present consists of a sunken triangular pit, having a 400-foot face, north and south and a 250-foot east and west face. At present, work is being carried on in the lower heavy beds of gray limestone.

The quarry is equipped with a crushing plant, consisting of No. 1 and No. 3 Gates crushers and accessories. The No. 1 crusher is used for crushing granite, which is shipped in from the southern part of the State. An average of eight men are employed. The output is mainly rubble and crushed stone.

The quarry north of the Natural Bridge road at Marcus avenue consists of a rectangular sunken pit 400 feet by 200 feet. The following is a description of the beds from top to bottom:

0-18 ft.	Loess stripping.
6 ft.	Hard, gray limestone. Works well.
8 ft.	Gray limestone. Crushed for macadam.
8 ft.	Light gray limestone, contains short tight seams.
1½-3 ft.	Soft, yellowish brown limestone, having a sandy texture.
3 ft.	Gray limestone in thin layers.
1½-2½ ft.	Hard limestone, known as "nigger ledge." Difficult to work. Used for crushed stone.
4 ft.	Two two foot beds of finely crystalline, light, gray limestone.
8 in.	Finely crystalline, light gray limestone used for curbing.
2 ft.	Dark colored limestone.
15 ft.	Fine grained, gray limestone, in beds from two to four inches in thickness.

In general, the stone is solid and compact. The product is chiefly crushed and building stone.

The quarry is equipped with a No. 4 crusher and accessories, an engine, boiler, steam pump and derricks. Two sizes of crushed stone are manufactured, one and one-half inch and screenings. About twenty-five men are employed.

THE SINCLAIR QUARRY & CONSTRUCTION CO.'S QUARRY.

This quarry, which is owned by George Penn, is located on the river bluffs one-fourth of a mile from Vigus Station, and is connected by side track with the St. Louis, Kansas City and Colorado railroad. The office of the company is at 413 Fullerton building, St. Louis.

The following is a description of the beds from top to bottom:

10-25 ft.	Loess stripping.
0-20 ft.	Fine grained limestone, in thin layers. At the south end of the quarry, the beds have been eroded away.
4 ft.	Fine grained, gray limestone, containing nodules of flint.
12 ft.	Gray limestone, in beds from four to six inches in thickness. Upper bed of twelve inches is a very good quality of dark gray, crystalline limestone.
4 ft. 3 in.	Bluish gray limestone, in beds about twelve inches thick.

The twelve-foot ledge exhibits a system of inclined joints striking north and south and east and west and dipping respectively 25-30° W. and 30° N. These do not occur in the beds either above or below.

The quarry is equipped with a No. 5 Austin crusher and accessories, a steam drill, derrick and other machinery necessary in working the stone. An average of forty men are employed from March to December. The products are chiefly crushed and building stone. The stone is now being used in the new Washington University buildings.

THE SKRAINKA QUARRY.

This quarry, which is owned by the Atlantic Real Estate Company and the Terminal Railway Association and operated by the Atlantic Quarry and Construction Co. of 806 Security building, is located just north of the railroad tracks at Scott and Montrose avenues. It has been in continuous operation since 1895, and consists of a rectangular, sunken pit 500 feet by 250 feet. The following is a section of the quarry from top to bottom:

10-15 ft.	Loess stripping.
10 ft.	Dark and light gray limestone, used for crushing.
2 ft. 10 in.	Crystalline, gray limestone, good quality.
11 ft.	Thinly bedded, fossiliferous, bluish gray limestone.
2 ft. 8in.	A solid bed of fine textured, gray limestone.
1 ft. 6 in.	Porous, yellowish gray limestone, containing specks of iron oxide.
2 ft. 6 in.	The upper half of this bed is gray limestone containing small nodules of chert. The lower half is a porous, yellowish colored limestone of poor quality.
5 ft.	Medium grained, crystalline, dark gray limestone, showing stratification planes from two to eight inches apart, along many of which the stone caps easily. Very good quality of stone.
4 ft.	Very fine grained, compact, dark gray limestone, having a splintery fracture.
1 ft. 6 in.	An irregular bed of dark gray limestone. Has a fine grained matrix, studded with small crystals of calcite.
1 in.	Blue shale.
2 ft. 8 in.	Very fine grained, compact, light gray limestone, containing small geodes of calcite. Breaks with an irregular fracture.
3 ft. 8 in.	Compact, light gray limestone. Breaks with an irregular fracture.

The stone from the lower beds of this quarry is used mainly for the manufacture of crushed stone. The dense compact texture, combined with the sharp fracture, makes it well suited for this purpose. From the upper beds very good rubble stone can be obtained.

The quarry is equipped with a No. 3 Gates crusher and accessories, a steam hoist, steam drills, steam pump, boiler and engine. The stone is loaded on cars having movable boxes which are hoisted by derricks to the surface. Here the stone is dumped into cars in which it is carried to the crusher. An average of forty men are employed at this quarry, which is operated the entire year.

This stone has been used in many of the St. Louis buildings, among which may be mentioned the National Bank of Commerce, Broadway and Olive streets; Brown building, 12th and Washington avenue; Goldman-Lesser building, 12th and Washington avenue; Bridge piers and abutments on Union street in St. Louis and in East St. Louis.

THE STOLLE STONE CO.'S QUARRY.

This quarry was opened in 1888 by the Glendale Quarry Co. Later it passed into the hands of the Grant Quarry Co., and at present it is owned and operated by the Stolle Stone Co. It is located three and one-half miles east of Kirkwood and one and one-fourth miles southeast of Glendale, and is connected by side track with the St. Louis, Iron Mountain and Southern railroad.

The quarry has a west face 650 feet long. The following is a description of the beds from top to bottom:

12-15 ft.	Gray to buff colored limestone, in beds from six to twenty-four inches in thickness. Used for rip rap, macadam, and rubble.
4 ft.	Fine grained limestone, known as the white ledge. Splits in places along suture joints. Contains an occasional dry. Bunches of fossil remains cause the stone to vary somewhat in hardness.
1 ft. 2 in.	Fine grained limestone known as the "leather ledge." This stone is very hard to spall, but splits well with plugs and feathers. Is used for footing and sewer intakes.
2 ft. 4 in.	Fine grained, fossiliferous, bluish gray limestone known as the "hard blue ledge." Difficult to saw but breaks well with plugs and feathers. Used mainly for bridge stone.
4 ft.	Fine grained, bluish gray limestone known as "soft blue ledge." Splits along shale seams into three beds of 12, 18 and 18 inches. A layer of partly decomposed chert nodules occurs along the bed. The stone contains an occasional dry.
3 ft.	Hard, dark gray limestone. In some portions of the quarry this bed feathers out and disappears. This stone works well.
4 ft.	Somewhat oölitic, light gray limestone. Splits eighteen inches from the bottom. Saws well. Is injured by frost when first quarried. Is known as the stockton ledge.

The major set of joints strike N. 45° E. and N. 45° W. They occur from twenty to fifty feet apart.

The stone from the upper part of the quarry is used mainly for rubble and is blasted with very little regard to the jointing planes. The stone from the lower part is used for building purposes, and careful attention is given to the jointing planes which facilitate the removal of the rock. The stone is split between these joints by plugs and feathers. It is also lifted from the bed by driving plugs along the bedding plane. In this manner, the quarry produces mill blocks without the use of channeling machines.

The lower beds, up to and including the white ledge, contain the most valuable stone, and are used almost exclusively for the better classes

of building constructions. When exposed to the atmosphere, the stone takes on a somewhat lighter color. The stone in the "Stockton" ledge has a very uniform color and has been used exclusively in the church at Webster Groves and in other buildings.

The quarry is equipped with modern machinery for cutting and dressing the stone, including four gang-saws, two of which are of an improved type built by the Bulhan Foundry Company of St Joseph. The equipment also includes a crushing plant, drills and other machinery necessary for quarrying and working the stone.

During the last four years this quarry has not been very active, the output being exclusively rubble stone. The quarry is worked from May to October.

LABORATORY EXAMINATION.

Chemical Analysis.—A sample of the limestone from what is known as the white ledge, was analyzed in the Bureau laboratory with the following results:

Insoluble	2.36
Fe_2O_3, Al_2O_3	.27
$CaCO_3$	96.09
$MgCO_3$	.90
Total	99.62

The above analysis shows this to be a very pure limestone, the chief impurity being silica which is included in the percentage of insoluble matter.

Physical Tests.—Two-inch cubes were examined in the laboratory to determine their physical properties with the following results:

Specific Gravity	2.672
Porosity	7.30 per cent.
Ratio of absorption	2.947
Weight per cubic foot	150.3 lbs.
Tensile Strength	1052.33 lbs. per sq. in.
Transverse Strength	2727.4 lbs. per sq. in.
Crushing Strength	17,095 lbs. per sq. in. on bed. 17,349 lbs. per sq. in. on edge
Crushing Strength of samples subjected to freezing test	16,246 lbs. per sq. in.

These tests indicate that the stone is very strong. The crushing strength and tensile strength are very high. The average crushing strength of the frozen samples was only 849 pounds per square inch less than that of the fresh samples.

THE WINTERS QUARRY.

This quarry, which is owned and operated by Nelson Winters of Marshall avenue and Tuxedo Park, is located at Old Orchard, west of Big Bend road and north of Dale avenue.

The quarry is situated on the west side of the hill and has a working face of about 200 feet. The lower five feet is a very fine grained, compact, bluish gray limestone, in beds from four to eight inches in thickness. Above this is an eight-foot ledge of gray limestone, in beds from two to fourteen inches in thickness. The stripping consists of from four to six feet of loess. The beds have an apparent gentle dip to the north. The principal products are crushed and building stone.

THE WADE BROS. CONSTRUCTION CO.'S QUARRY.

This quarry, which was opened in 1890, is located at McCauslin avenue and Moonen streets. The office of the company is located at 2272 Old Manchester Road.

The quarry consists of a rectangular, sunken pit 250 feet by 350 feet, with a vertical face of about 60 feet. The stripping, consisting of twelve feet of loess, has been removed for a considerable distance back from the face of the quarry. The following is a section of the quarry from top to bottom:

6 ft.	Gray, sandy textured limestone.
4-6 ft.	Solid, bluish gray limestone, having a sandy texture.
2 ft.	Fine grained, bluish gray limestone. Very brittle.
1 ft. 8 in.	Fossiliferous, bluish gray limestone.
12 ft. 6 in.	Finely crystalline limestone in beds from four to eight inches in thickness. The heaviest beds are near the top.
25 ft.	Finely crystalline, white limestone, in beds from three to six inches in thickness.
5 ft. 6 in.	Fine grained, flinty limestone.
5 ft.	Bluish gray limestone.
6-8 ft.	Somewhat impure, bluish gray limestone, in beds from two inches to one foot in thickness.

The lower two ledges are below the level of the present working face, the upper one is a natural drain through which the water is carried off.

The major joints strike north and south, N. 70° E. and N. 80° E.

The stone is not injured by the frost and can be quarried at all seasons of the year. Analyses, which the company had made of the limestone from different parts of the quarry, show 98 per cent. calcium carbonate. Such portions are sufficiently pure to be suitable for furnace flux. The output of the quarry is chiefly rubble and crushed stone. The equipment consists of a No. 3 Gates crusher and accessories, steam drill, engine, boiler and necessary hand tools. About fifteen men are employed.

THE WORKHOUSE QUARRY.

The largest quarry in St. Louis is located on Meramec street just east of the workhouse and is operated by the city. An average of two hundred convicts are worked regularly in this quarry. The only product

Crushing macadam by Hand, St. Louis, Mo.

at present is crushed stone. About six cars of stone are shipped each day and are used in repairing the city pavements.

This quarry has an opening about 850 feet by 325 feet. The beds have an apparent gentle dip to the southwest. The following is a section of the quarry from top to bottom:

10-30 ft.	Loess stripping.
33 ft.	Limestone in beds from one to five feet in thickness. Most of the stone contains flint nodules. It makes very good macadam, but is not suitable for buildings. These beds have been removed by erosion at the north end of the quarry.
3 ft.	Fine grained, compact, gray limestone in two beds. The stone weathers to a white and stands out in marked contrast with the beds on either side.
4 ft. 6 in.	Heavy bed of very finely crystalline, gray limestone. A good building stone.
25 ft.	Granular to crystalline, gray limestone. Containing flint nodules and suture joints. Cannot obtain much building stone from this portion of the quarry.
7 ft. 6 in	Finely crystalline, light gray limestone. Rather porous. A suture joint occurs one foot from the top. Contains occasional nodules of flint.
7 ft. 10 in.	Medium grained, crystalline, gray limestone. Contains suture joints from six inches to one foot apart.
5 ft. 8 in.	Gray, finely crystalline limestone, containing small sutures. Ledge shows cross bedding.
3 ft. 6 in.	Coarsely crystalline, drab colored, magnesian limestone. Contains large crystals of calcite in a finely crystalline matrix.
3 ft. 3 in.	Dark, fossiliferous limestone. The lower ledges are rather impure. The stone in a number of the ledges is soft and when fresh is often carved by the convicts.

A small crushing plant has recently been erected at the quarry.

THE ZEISS QUARRY.

This quarry, which is located west of Broadway on Keiser road, is operated by Henry Zeiss of 9125 Minnesota avenue. It has a working face along the bluff of 650 feet. It is reported that this quarry will not be operated after the present year. The following is a section from top to bottom:

25-30 ft.	Loess stripping.
8 ft.	Gray limestone in thin beds.
5 ft.	Crystalline, gray limestone, containing clay pockets. Near the top, the stone has a dark reddish brown color.
2 ft. 2 ft. 4 in. 2 ft. 4 in.	Finely, crystalline, gray limestone. Bottom bed splits in middle.
6 ft. 6 in.	Finely crystalline, gray limestone in beds from four to ten inches in thickness. Is used, in part, to make caps and sills. A very good building stone.
4 ft.	Gray limestone. Shelly.

The major joints strike N. 85° E. and N. 20° W. This quarry has a natural drainage.

The stone has been used for buildings, macadam, furnace flux and the manufacture of mineral wool. For furnace flux it brings sixty cents per ton. The quarry employes about twenty men.

STE. GENEVIEVE.

Very few counties in the State have within their borders as many different geological horizons as Ste. Genevieve. The pre-Cambrian, Ordovicion, Silurian, Devonian and Mississippian are all found in this county. Most of these formations contain stone suitable for building constructions. The river bluffs, north of the city of Ste. Genevieve, are the most favorably situated for quarrying operations. The rugged topography of the land west of the river bluffs also makes quarrying comparatively easy. Transportation, both by river and by railroad, can be had. The limestone and sandstone of the Cambro-Ordovician formations, which outcrop over a large part of the county, are quarried locally in many places for chimneys, fire-places and foundations. In some places, the limestone is very finely crystalline, having much the appearance and many of the characteristics of marble. The Archimedes and St. Louis limestones, which occur in the bluffs along the Mississippi river, have been quarried quite extensively. The United States government operates one of the largest quarries in the State in the St. Louis limestone two miles above Ste. Genevieve.

The first use of the St. Louis limestone in the manufacture of quicklime was in 1840, the product being shipped by boat to various points along the Mississippi river. It is still being used for this purpose. The stone disintegrates rapidly when exposed to the weather and therefore is not desirable for building. The quarries in this formation will be described more in detail in a later report on the "Lime and Cement Industries."

South of Ste. Genevieve, the "Ferruginous sandstone" has been quarried extensively in the past, but at present it is not being used. The following are brief descriptions of the individual quarries which were inspected in this locality.

THE EGYPTIAN MARBLE CO.'S QUARRY.

In 1892 the Egyptian Marble Company began to develop the marble deposits in the United States Surveys 2074, 2083, 3164, T. 37, R. 8 E., between the upper tributaries of the Aux Vases and Saline creeks. Development work was carried on until March, 1893, since which time nothing has been done. This company made several small openings. The largest has a rather irregular shape approximating 50 feet square by 25 feet in depth. The following is a description of the beds from top to bottom:

United States Government quarry, Ste. Genevieve, Mo.

5-7 ft.	Clay stripping
4 ft.	Finely crystalline, mottled gray limestone.
6 ft.	Red and green shale, having a variegated color and containing calcareous concretions.
6 ft.	Variegated red and gray, finely crystalline, mottled marble. Very brittle.
7 ft.	Finely crystalline, yellowish magnesian limestone.

The limestone in this quarry is all finely crystalline and contains narrow seams of calcite. It is brittle and must be handled very carefully to prevent breaking. It takes a fairly good polish and has been used for table tops and interior decorations to buildings.

The quarry contains a very high percentage of unsalable stone, on account of which it cannot be worked profitably.

THE COUNTY QUARRY.

This quarry, which is located one mile south of Ste. Genevieve, has been worked intermittently during the last four years. It is located on land owned by Peter Schneider of St. Louis. The entire output is crushed rock, used in the building of macadam pavements. The following is a description of the beds from top to bottom:

11 ft.	Bluish gray, finely crystalline limestone. Splits into thin beds when blasted.
1 ft. 2 in.	Solid, fine grained, fossiliferous, gray limestone.
1 ft.	Solid bed of compact, bluish gray limestone. Separated from the bed above by two inches of shale.
6 ft.	Finely crystalline, blue limestone, splits into beds from two to four inches in thickness. Thin seams of shale occur along the bedding planes.

Two sets of joints about twenty feet apart strike respectively N. 28° E. and N. 57° W.

This stone has been quarried at a number of different places south of the city and used as a road metal. These quarries are opened up at intervals so that it will not be necessary to haul the stone very far.

THE GOVERNMENT QUARRY.

The United States government operates a quarry two miles nortl. of Ste. Genevieve in No. 146, T. 38, R. 9 E., United States Survey. The quarry consists of two openings separated by a narrow strip of rock. Together they extend one-half to three-fourths of a mile along the river bluff, constituting by far the largest quarry now operated in the State. The quarry was opened in 1892 and has been worked each year when river improvement work has been done. The land is owned by Andrew Wilder and Herman Weber to whom the government pays two cents a yard royalty.

The strata dip from 2-3° south. With the exception of from fifteen

to twenty feet of flinty limestone, constituting the lower beds of the north opening, the same strata are quarried in both.

The following is a description of the beds in the south opening from top to bottom:

20-40 ft.	Clay stripping.
5 ft.	Thinly bedded, shelly, dark gray limestone.
16 ft.	Crystalline, gray limestone. The different beds vary somewhat in texture.
14 ft.	Similar to beds above. Separates into a number of beds, which vary in thickness up to two feet.
16 ft.	Finely crystalline, gray limestone, showing cross bedding.
5 ft.	Soft, argillaceous stone. Weathers very rapidly. Has a decided blue color.
6 ft.	Thick bedded dark gray, medium to coarsely crystalline limestone which works well.
4-6 ft.	Finely crystalline, gray limestone, containing small black nodules of flint.
3 ft.	Gray limestone, containing an occasional nodule of black flint. Consists of an upper bed of one foot and a lower of two feet.
12 ft.	Thinly bedded, finely crystalline, gray limestone, containing small, black flint nodules. This stone requires very little sledging after being blasted.
6 ft.	Heavily bedded gray limestone. This ledge is difficult to work.

Fluorite was noted along a number of the minor joints. A small amount of Bauxite is reported as occurring in the quarry, although none was noted when the quarry was inspected. The stone is covered with very heavy stripping, which is removed very cheaply by hydraulic power, the clay being washed over the face of the quarry into the river.

The entire output is used for rip rap along the Mississippi river. The stone is hauled by cars to the river where it is loaded upon large river barges. The St. Louis and San Francisco railroad now skirts the base of these bluffs, affording an excellent opportunity for getting out crushed stone for ballast and concrete work.

About 280 men are employed and 1,000 cubic yards of crushed stone are produced per day of eight hours. Employees are paid $1.12 per day and board or $1.64 without board. Geo. W. Crane is superintendent of the quarry.

THE AUX VASES SANDSTONE QUARRIES.

Formerly, a number of quarries were operated in the Aux Vases sandstone, about four miles south of Ste. Genevieve. Large quantities of this stone were used in the abutments of the Eads bridge, at St. Louis; in the Iowa State Capitol, at Des Moines; and in the Equitable and McLean buildings in St. Louis. At one time the Richardson quarry, located in United States Survey 307, T. 37, R. 9 E., and the Bogy quarries, located in United States Survey No. 3221, T. 37, R. 9 E., were operated on an extensive scale. The former employed from 400 to 500

men and the latter from 300 to 400. The Wilder quarry, located in United States Survey 307, T. 37, R. 9 E., also produced considerable stone.

The Richardson quarry, which was the only one inspected, has been opened along a bluff for a distance of about 650 feet and at the south end has been worked into the hill 210 feet. It has a vertical face of thirty-two feet at the south end, while at the north end the depth is much less. The stone is covered with from twenty to thirty feet of loess stripping. The upper seven feet is very shelly stone and was removed by blasting. Underneath this the stone was all channeled. The upper three feet of the channeled portion is rather shelly and is unfit for constructional purposes.

Stratification planes are especially promient in some parts of the quarry and for this reason care should be exercised in selecting the stone. Only one vertical joint was observed. This was near the south end of the quarry and it had a strike of N. 50° W. The stone is fine grained, light buff to yellowish in color, and rather soft when first quarried.

The other quarries in this formation contain stone which is very similar to that above described. The only difference is in color.

ST. CHARLES

THE DIRKER QUARRY.

This quarry, which is owned by Dirker Bros., and operated by Micheal Hanson, is located one mile south of St. Charles on the Missouri, Kansas and Texas railroad.

The face of the quarry is 500 feet long, but at present it is being worked only near the middle. The stone is a bluish gray, crystalline limestone similar to that at the Hoelcher quarry. The middle of the quarry is covered with ten feet of clay stripping.

The quarry is equipped with a small crusher. The principal products are crushed stone and rubble.

THE HOELCHER QUARRY.

This quarry, which is owned by Fred Hoelcher and operated by Fred Elsner, is located two miles southwest of St. Charles on the west side of the Missouri, Kansas and Texas railroad. Formerly the quarry was operated quite extensively by Mr. J. Short for government work, but up to September, 1901, it had been idle for a number of years. It has been opened along the east side of the bluff for a distance of about 325 feet. The following is a section from top to bottom:

4-6 ft.		Loess stripping.
7 ft.		Sandy, argillaceous, yellow limestone of inferior quality. Cannot be used.
2 ft.	1 in.	Finely crystalline, bluish gray limestone, containing calcite nodules and geodes. Splits into three beds seven to eight inches in thickness
	8 in.	Soft yellowish limestone, containing greenish spots. Two inches of shale at top.
1 ft.	6 in.	Finely crystalline limestone. Works into large blocks.
1 ft.	4 in.	Fine grained, compact, dark gray limestone. Has an uneven splintery fracture.
3 ft.	3 in.	Similar to layer above. Splits in middle of bed Breaks with uneven fracture Used mostly for macadam.
	10 in.	Hard, fine grained, bluish gray limestone.
2 ft.		Fine grained, compact, gray limestone. Splintery fracture.
3 ft.		Fine grained, bluish gray limestone. Works well.

The lower ledge of three feet is not being quarried at present. In general, the stone is compact and, although it breaks rather irregularly and does not work easily into rectangular pieces, it is a durable building stone. The quarry is not worked very extensively at present. Hand tools are used. The output is chiefly rubble.

SEDALIA.

The quarries which are operated at the present time in the vicinity of Sedalia are owned by Rymer Bros., J. W. Marsh, James Jenkins, Benjamin Johnson and Mr. McEnroe. A number of abandoned quarries occur in this locality. The quarry at Georgetown, four miles north of Sedalia, is said to contain excellent building stone, but its distance from the market makes it unprofitable to work. Along the Georgetown road, north of Sedalia, a number of quarries have been opened up which are now abandoned. The stone from one of these was, at one time, used by the city as a road metal.

In most of the quarries, the stone is partly Burlington and partly Chouteau. The Burlington, which lies immediately above the Chouteau, has been entirely removed by erosion in some parts of this area. At the Rymer, Jenkins and Johnson quarries, all of the stone belongs to the Chouteau formation. At the McEnroe quarries, the upper beds are Burlington limestone and the lower Chouteau. All of the beds in the Marsh quarry belong to the Burlington.

The Burlington limestone is the typical coarse grained, crystalline, fossiliferous variety, so characteristic of this formation. Here, as elsewhere, it produces an excellent quality of white lime. The Chouteau underlies the region about Sedalia and the outcrops indicate a thickness of from forty to ninety feet. In general, it occurs in thick, massive beds with very few bedding or stratification planes. The stone is a fine

grained, compact, siliceous, magnesian limestone, having a uniform light drab color, except along the weathered joints and bedding planes, where it has a buff tint. Large chert nodules are disseminated irregularly through the stone. It breaks with a conchoidal fracture and is more difficult to quarry than that which is well stratified.

THE JENKINS QUARRY.

This quarry is located at the corner of 22nd and Engineer streets, near the southeast limits of the city. It has a north face 250 feet long and twenty feet high. All of the stone belongs to the Chouteau formation.

The following is a description of the beds from top to bottom:

6 ft.	Chert, clay and soil stripping.
12-14 ft.	Fine grained, compact limestone. The lower six feet has a uniform blue color and contains very little chert. Above this occurs four feet which contains numerous chert nodules. The upper two to four feet has a buff color, due to weathering. The stone in the lower six feet is the best in the quarry.
5 ft.	Blue, fine grained limestone, somewhat harder than that in the upper part of the quarry. Chert nodules occur along the bottom of this bed.

The stone breaks with a conchoidal fracture and when blasted or split, it usually breaks toward any chert nodule which may occur in the block near the breaking surface. This manner of breaking causes considerable waste in cutting and dressing. Unless seasoned the stone is liable to injury from alternate freezing and thawing.

A greater part of the stone is used for foundations, although stone suitable for caps, sills and ashler blocks can be obtained. Any dimensions can be obtained from the heavy beds. Cubical blocks 12x14 inches on a side are quarried and cut for foundations. The spalls from the large blocks are used for well cribbing. The rough stone sells for $1.00 per perch delivered, while the cubical blocks bring 15 cents apiece. From two to fifteen men are employed, depending upon the demand for stone. This quarry was not in operation during 1903.

THE JOHNSON QUARRY.

This quarry, which is located four miles west of Sedalia, consists of two openings, in which several beds, from four to twelve inches in thickness, are being worked. The stone is a fine grained limestone belonging to the Chouteau formation. It is used for curbing, sidewalks and foundations. The quarry has been opened about ten years.

THE McENROE QUARRY.

This quarry, which is located about three and one-half miles northeast of Sedalia and one and one-half miles east of the Marsh quarry, is

operated by Charles Meyers. It is situated on the south side of a hill and has a face about 325 feet long. The following is a description of the beds from top to bottom:

2-10 ft.	Bouldery limestone. Chert and clay stripping.
4 ft.	Coarsely crystalline, fossiliferous limestone. The upper part of the bed has a buff color and the lower part a blue. Contains chert nodules, especially in the upper part. Two suture joints were observed.
5 ft.	Medium to coarse grained, fossiliferous, bluff and blue colored limestone. Will split along a suture joint fourteen inches from the top.
4 ft. 2 in.	Blue, coarsely crystalline, fossiliferous limestone, containing chert and calcite nodules.
6 ft.	Bluish colored, medium grained limestone. Splits into beds from four to eight inches in thickness. These beds become tighter with depth.

The major joints strike N. 55° E. and N. 60° W. The minor joints strike N. 15° W. and E. and W.

At the time the quarry was inspected the stone was being used exclusively for the foundation course to macadam pavements near Sedalia. River gravel was being used for the surface and the combination is said to produce an excellent pavement.

THE RYMER BROS. QUARRY.

This quarry, which is located two miles north of Sedalia, is owned by Mrs. Heidenfelter and operated by Edward and J. W. Rymer. It was opened in 1894, since which time it has been operated each year. It consists of two openings, only one of which is now being worked. The opening which is active has a face 50 feet long and 10 feet in height. It consists of two thick beds of Chouteau limestone, covered with from two to five feet of chert and clay stripping. The upper bed consists of six feet of fine grained, compact limestone, varying in color from blue to buff, the upper portion being buff and the lower blue. The buff colored stone is softer than the blue. Large chert nodules are disseminated throughout the bed. The lower bed in the quarry consists of four feet of fine grained, bluish gray limestone. It contains an occasional chert nodule, but they are not as abundant as in the upper bed.

The joints are not important and very little attention is given them in quarrying. The most prominent strike east and west and N. 45° E. Short tight seams, known as dries, occur in the stone.

The stone breaks with a conchoidal fracture and follows the chert nodules in both the blasting and breaking with plugs and feathers. The beds do not split readily along the bedding planes and are rather thick for quarrying without machinery. The stone has the appearance of being strong and durable.

The entire output is being used for foundations, although ashler

blocks might be obtained, especially from the lower bed. From three to five men are employed during the summer months.

LABORATORY EXAMINATION.

Chemical Aanalysis.—The following is a chemical analysis of the Chouteau limestone from this quarry:

Insoluble	17.69
Fe_2O_3, Al_2O_3	1.08
$CaCO_3$	49.21
$MgCO_3$	31.57
Total	99.55

Physical Tests.—Two-inch cubes of stone from this quarry were examined in the laboratory with the following results:

Specific Gravity	2.757	
Porosity	13.38	per cent.
Ratio of Absorption	5.619	
Weight per cubic foot	149.3	lbs.
Tensile Strength	792.	lbs. per sq. in.
Transverse Strength	2118.07	lbs. per sq. in.
Crushing Strength	12,995.3	lbs. per sq. in. on bed.
	11,811	lbs. per sq. in. on edge.
Crushing strength of samples subjected to freezing test	13,027.6	

Although this stone has a porosity of over 13 per cent., the result of the freezing test shows that the strength is very little affected by weathering. The stone is abundantly strong to be used in most buildings and has the transverse strength which indicates its suitability for caps and sills.

SPRINGFIELD.

The principal quarries in and near Springfield are quarrying limestone belonging to the Burlington formation. According to Dr. E. M. Shepard,* this formation covers a greater part of the S. W. ¼ of Greene county and contains a maximum thickness of 215 feet. Shepard** recognizes three divisions of the Burlington in this county.

1st. A heavy bedded chert, or alternating thin beds of shaly limestone and chert, from a few to forty feet in thickness.

2nd. A coarse grained, crystalline, soft, grayish colored limestone, carrying rather soft, lenticular masses of chert, from a few inches to a foot or two in diameter. In places the chert is absent. The beds are characterized by having suture joints and the stone is alternately fine and coarse.

*Mo. Geol. Sur., Vol XII, Geol. of Greene Co., by Dr. E. M. Shepard, p. 115.
**Ibid, p. 113.

3rd. A decidedly shaly horizon much harder than the upper two. These beds have a thickness of from fifty to eighty feet and are remarkably pure limestone, containing only traces of silica, alumina, magnesia and iron. Chert nodules are present and increase as the formation is followed to the southeast.

The most important quarries in this locality are operated by H. F. Denton, the Marble Head Lime Co., J. D. Coutlet and R. S. Denny.

With the exception of the Hollman quarry, the stone differs very little in its general characteristics, being rather coarsely crystalline, blue to light gray and fossiliferous, containing layers and occasional nodules of flint. The stone is suitable for building purposes, but is too soft for macadam. It might be used for foundations, but even in this position a harder stone is more desirable. The following are descriptions of the individual quarries:

THE DENTON QUARRY.

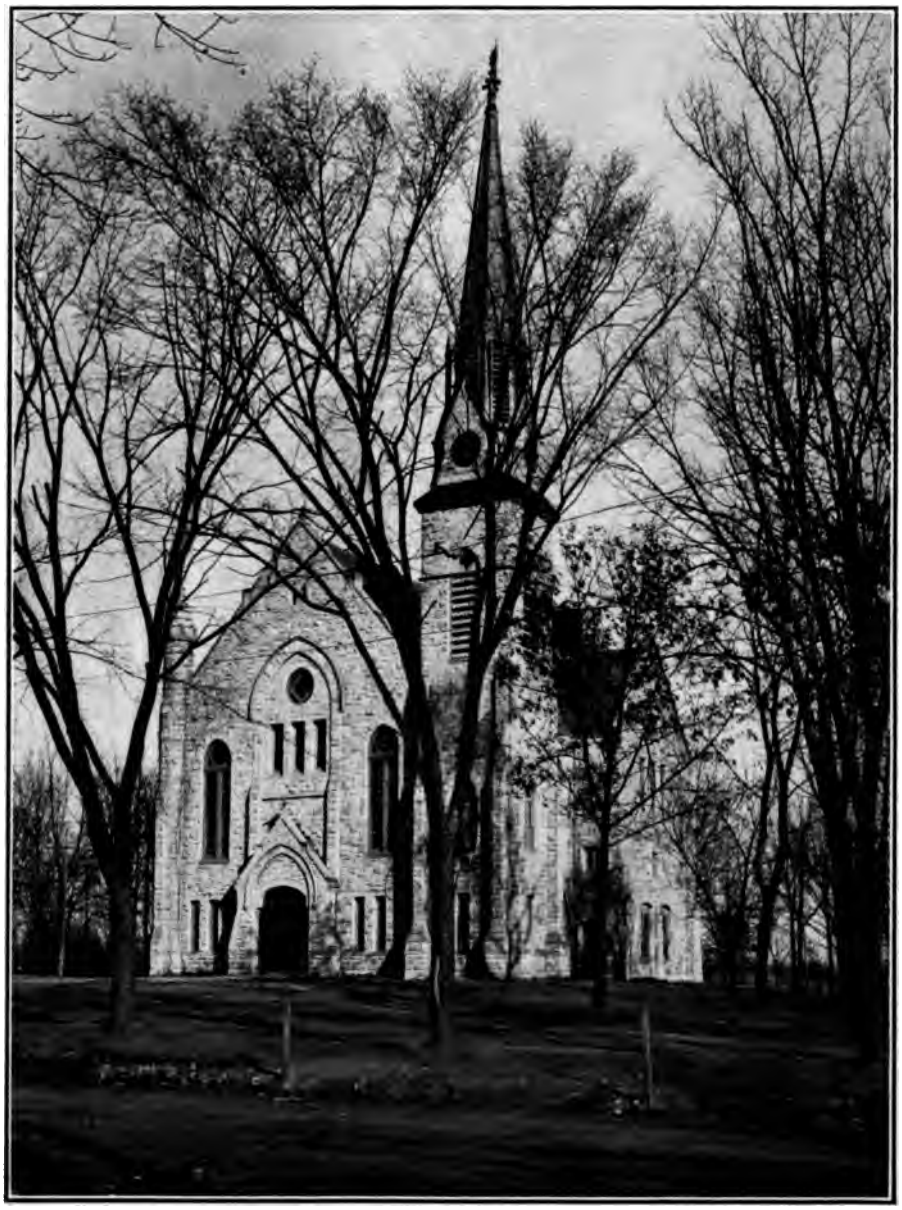
This quarry is located between West Walnut and College streets in the West End addition. It has a west face 200 feet long and has been worked into the hill about 150 feet. The following is a description of the stone from top to bottom:

1-2 ft.	Red clay and chert stripping.
8 ft.	Coarsely crystalline, gray, fossiliferous limestone. This bed has suture joints from two to eight inches apart. At either end of the quarry it is bouldery on account of its nearness to the surface.
6 ft.	Limestone, containing numerous flint nodules. It is coarse and fine grained and contains suture joints.
3 ft. 6 in.	Bluish gray, very coarsely crystalline limestone. Occasional flint nodules occur near the middle of the bed. Here there is also a suture joint along whch the stone will split.
14 ft.	Bluish gray, coarsely crystalline, fossiliferous limestone. Contains tight suture joints. A layer of flint nodules occurs at the top of the bed. The stone is difficult to work but is said to be the best stone for macadam.
6 in.	Bed of chert.

The major joints strike N. 45° E.

The stone is quarried without machinery, a hand-crane being used to lift the larger blocks. The quarry is equipped with a crushing plant which has not been used for some time. This stone was used in the construction of the macadam pavement leading to the National Cemetery. It has a pleasing color and can be used to advantage for constructional purposes.

North of this quarry is an abandoned opening owned by the John O'Day estate. The stone is very similar to that in the one just described. It has not been operated for several years.



BURLINGTON LIMESTONE.
Chapel at Drury College, built out of stone quarried at Springfield.

LABORATORY EXAMINATION.

Chemical Analysis.—The following is a chemical analysis of this limestone. Attention is called to the very small percentage of impurities, such as silica, iron and alumina:

Insoluble	.36
Fe_2O_3, Al_2O_3	.13
$CaCO_3$	99.34
$MgCO_3$	.227
Total	100.057

THE HOLLMAN FLAGSTONE QUARRY.

This quarry, which was opened thirteen years ago by Geo. Hollman, is located nine miles northeast of Springfield. It is now owned by R B. Coutlet and operated by J. D. Coutlet. It is located in a valley just north of the Little Sac creek, and has a total face of 400 feet, consisting of beds of limestone from four to six inches in thickness.

The stone is a compact sub-crystalline, bluish gray limestone, having a rather fine texture. Blue shaly seams occur in the stone, especially in the lower beds. The stone in the lower part of the quarry contains thin seams of calcite known as "glass" seams. All of the stone contains small nodules of pyrite, but these are most common in the two lower beds. The stripping consists of four feet of soil and chert.

The major joints, which strike N. 75°-80° E., and are from fifteen to sixty feet apart, have determined the direction in which the quarry is being worked. The stone also contains dries. In quarrying, the stone is split between the joints, with plugs and feathers, to any desired width. It is then lifted and broken into flagging or curbing of any desired dimensions. The stone is very durable when used for curbing or sidewalks, as shown by streets in Springfield on which it was laid ten to thirteen years ago.

LABORATORY EXAMINATION.

Chemical Analysis.—The following is a chemical analysis of this stone which shows it to be somewhat arenaceous and not as pure as that occurring in the Denton quarry:

Insoluble	4.51
Fe_2O_3, Al_2O_3	.52
$CaCO_3$	92.24
$MgCO_3$	2.35
Total	99.62

Physical Tests.—Two-inch cubes were examined in the laboratory to determine the physical qualities of this stone with the following results:

Specific Gravity	2.715
Porosity	.927 per cent.
Ratio of Absorption	.274
Weight per cubic foot	168.1 lbs.
Crushing Strength	20,779 lbs. per sq. in. on bed. 19,580 lbs. per sq in. on edge.
Crushing strength of samples subjected to freezing test	17,814 lbs. per sq. in.

These tests show the stone to have an especially high crushing strength; being surpassed only by the limestones from Noel and Jackson. The cubes subjected to the freezing and thawing test lost 2.965 pounds per square inch, as shown in the above table. It is interesting again to note that the low porosity of less than one per cent. is accompanied by a correspondingly high loss in strength through freezing and thawing.

THE TINDELL QUARRY.

This quarry, which is owned by A. Tindell and operated by R. S. Denney of 914 Dale street, is located at the north end of Jefferson street. It has been operated about fifteen years and has a face of about 125 feet. It consists of two ledges, the lower of which contains nine feet of coarsely crystalline, gray limestone of Burlington age. This lower bed separates into two layers four feet three inches and four feet nine inches in thickness. These layers can be split into blocks about twelve inches in thickness which make very good ashler. Suture joints occur from two to eight inches apart. Coarse and fine grained layers alternate in this stone.

The upper ledge is eight feet in thickness and works into three beds. The stone in these beds is more coarsely crystalline and more uniform in texture than that in the lower bed. It contains suture joints from four to ten inches apart. Occasional chert nodules occur near the north end of the quarry. The stone is suitable for heavy rubble masonry or foundations, such as have been used in the base of the water tower in Springfield.

THE MARBLE HEAD LIME CO.'S QUARRY.

The quarry owned by this company is located on Phelps between Sherman and Springfield avenues. The quarry consists of a rectangular, sunken pit about 1,000 feet by 250 feet. The portion which is worked at present is about 250 feet square and has a vertical face of 57 feet. The stone from this quarry is used extensively for the manufacture of quicklime, the plant for this purpose being the second largest in the State. The following is a description of the stone from top to bottom of the quarry:

8 ft.	Coarsely crystalline limestone, containing suture joints about twelve inches apart along which the stone is split with plugs and feathers.

12 ft.	Gray, coarsely crystalline limestone. Very few suture joints and no chert nodules occur in this bed. This stone makes good ashler blocks, which can be obtained in large dimensions. It is well suited for this purpose. This and the bed immediately above are used exclusively for building stone.
2 ft. to 6 in.	Bed of chert.
37 ft.	Gray, coarse to fine grained, crystalline limestone. The texture of the stone varies. Suture joints occur from two to twelve inches apart and vary from very fine pencil lines to two inches in size. The stone is used chiefly for the manufacture of quicklime. Some chert nodules, especially near the bottom of the bed.

The upper portion of the quarry has been leased to Mr. H. Hanson who works it without machinery. Rubble stone is the chief product.

The major joints strike N. 40°-45° E.

The lime-kilns are located at the west end of the quarry. The stone is hauled to the kilns over an inclined tramway. The equipment consists of a gasoline engine, a modern air compressing plant, Ingersoll drills, centrifugal pump and other necessary machinery. The plant has a cooperage, in which the barrels in which the quicklime is shipped, are made. About 50 men are employed in the quarry.

The broken flint and waste limestone, which are hauled out of the quarry and dumped near the kilns, are removed by the city and used as a road metal.

RÉSUMÉ.

The limestone in the quarries at Springfield has a uniform color and a texture which makes it well adapted for constructional work. However, the abundant chert nodules which occur in some parts of nearly all the beds practically preclude the possibility of working the quarries exclusively for this purpose. Channeling machines cannot be operated successfully and quarrying by hand is too expensive.

The limestone has been used for sills, caps and ashler blocks in many of the buildings in Springfield. Drury College Chapel and St. Johns Episcopal church were erected entirely out of Springfield limestone. The suitability of the stone for this purpose is well illustrated by these buildings.

The purity of the limestone and its coarse texture make it very valuable for the manufacture of quicklime. That which is manufactured by the Marble Head Lime Co. is as pure and white as any lime in the State.

SWEENEY.

THE MISSOURI, KANSAS & TEXAS RAILROAD COMPANY'S QUARRY.

This quarry, which is located about three miles east of Clifton City, in secs. 4 and 9, T. 46, R. 19 W., is owned by Mrs. Lou Streit and Mr.

Ed. Sweeney and operated by the Missouri, Kansas and Texas railroad. Mr. J. C. Strine of Clifton City is superintendent and manager.

This quarry was opened in 1889 and has been operated each summer since, with the exception of 1893, 1896, 1899 and 1900. It has a face 700 feet long and from 70 to 100 feet high and has been worked into the hill about 200 feet. The stone is limestone belonging to the Burlington, Chouteau and Devonian formations. The following is a description of the beds from top to bottom:

27 ft.	Coarsely crystalline, fossiliferous Burlington limestone; color varies from a blue to a buff. Consists of two ledges of twelve and fifteen feet.
1 ft.	Bluish green shale.
38 ft.	Chouteau limestone. Blue, fine grained and compact. Consists of two beds, respectively eighteen and twenty feet in thickness. The lower bed of twenty feet contains very few chert nodules and has a uniform blue color. The upper eighteen feet contains more chert and breaks with a conchoidal fracture.
41 ft.	The upper twenty feet is a dark bluish gray limestone, which can be separated into beds from four to six feet in thickness. Contains disseminated chert nodules. The lower three feet is a solid bed of good stone which might be used for constructional purposes. Underneath this occurs four feet of dark gray, fine grained limestone, in beds from two to five inches in thickness. Contains many chert nodules. Beneath this, is a four foot bed of dark gray, fine grained limestone, containing many cavities filled with a green, shaly material. The lowest ledge is a dark gray, fine grained, crystalline, compact limestone thirteen feet in thickness. It contains small veins of calcite. Two small suture joints occur a little below the middle of the ledge.

No attention is paid to the joints in quarrying. The major set strikes N. 40° E., while two minor sets strike N. 10° E. and N. 40° W.

The stone from the Burlington and Chouteau beds is suitable for buildings, bridge abutments, retaining walls and other constructional purposes. At present all of the stone is being crushed for ballast and concrete.

The quarry face is broken in the middle by a thirty-foot seam of blue shale and sandstone, which are of no value and only entail expense for their removal. Iron pyrites is abundant in some parts of the quarry.

The equipment consists of modern machinery, including steam drills, boilers, engines and crushing plant. The crushing plant consists of No. 4 and No. 5 Gates crushers with elevators and screens, and has a capacity of about 400 cubic yards per day. The expense of operating these crushers is much greater than it would be to run a single crusher, having a capacity of the two small ones.

About seventy men are employed at this plant. About 95,000 cubic yards of broken stone was produced in 1901. It is separated into two

sizes known as screenings and macadam. The entire output is used for railroad work.

TROY.

Two quarries are located in the vicinity of this city, which are owned respectively by Mr. E. G. Hammond and Mr. H. Behreus. These quarries are both located about one-fourth of a mile south of the depot, in sec. 36, T. 49, R. 1 W., and are just west of the St. Louis and Hannibal railroad. The stone is very similar in both quarries and occurs in well stratified beds of a very convenient thickness for working by hand.

THE BEHREUS QUARRY.

This quarry, which was opened about ten years ago, has a north face of about 100 feet. The following is a description of the stone from top to bottom:

4 ft.	Reddish clay stripping, containing a layer of chert.
8 ft.	Buff colored limestone, containing small nodules of chert. Splits into thin layers and is used for well rock.
2 ft.	Bluish, crystalline fossiliferous limestone, containing chert nodules. Splits into thin layers, which are used chiefly for well rock.
2 ft. 9 in.	Blue, fossiliferous limestone. Splits into three beds eight inches, six inches and one foot six inches in thickness. Fine suture joints occur in this bed.
1 ft. 7 in.	Dark blue limestone. A four inch layer of chert occurs at the top.
10 in.	Dark blue, crystalline limestone. A fine suture joint occurs near the bottom of the bed. The upper two inches of this bed has a buff color.

The joints strike N. 65° W. and E. and W. They are not very prominent and are but little used in quarrying. The beds in the upper part are used for well and light foundation work. The thicker beds, that are free from chert, are used for broken ashler and range work.

THE HAMMOND QUARRY.

This quarry, which is located just west of the Behreus quarry, was opened in 1876 and has furnished a greater part of the stone used in this locality. It has a face about 150 feet long and 12 feet high. The stone is similar to that in the previously described quarry, although the beds are somewhat thicker. The following is a description of the beds from top to bottom:

2 ft.	Soil stripping.
4 ft.	Buff colored, crystalline limestone, containing numerous chert nodules.
1 ft. 2 in.	Blue, crystalline, fossiliferous limestone.
6 in.	Blue shale.
3 ft	Light blue, fossiliferous limestone, containing white, siliceous spots. Splits into six and eight inch beds.
2 ft. 2 in.	Blue, medium grained, crystalline, fossiliferous limestone containing chert nodules.

The principal joints strike N. 40° E. and N. 50° W.

The stone is suitable for well rock, light foundations and broken ashler. Where used in ashler masonry, it looks well. It is also well adapted for caps, sills and other trimmings to brick buildings. The rock face finish is very attractive and preferable to hammer dressed work.

WALNUT GROVE.

THE MUGEN QUARRY.

This quarry, which is located midway between Walnut Grove and Phenix, on the west side of the Kansas City, Ft. Scott and Memphis railroad, is owned by Pat Mugen. It has been opened about 300 feet east and west and 200 feet north and south. The stone has been used exclusively for the manufacture of quicklime, which is burned in a continuous kiln.

The following is a description of the beds from top to bottom:

0-1 ft.	Stripping.
6 ft.	Gray, coarsely crystalline, fossiliferous limestone. Occurs in beds from two to six inches in thickness.
16 ft.	Bluish gray limestone, varying in texture from fine to coarse grained. The variations in texture occur between what appear to be beds, although there is no parting plane between the layers of different texture. The stone contains suture joints which vary in size from one-eighth to one and one-half inches. The largest suture joints occur near the middle of the bed and are from eighteen to twenty-four inches apart. Smaller suture joints occur between the larger ones. The stone contains dark spots near the middle of the bed. Occasional flint nodules occur near the south end of the quarry.
5 ft. 6 in.	The stone in the upper part is coarse grained, while that in the lower part is fine grained. These are separated by suture joints. The upper eighteen inches contains many flint nodules.

The floor of the quarry is a layer of flint which overlies a fine grained limestone which it is intended later to work. At the time this quarry was visited the Viernow and Meysenburg Cut Stone Co. of Carthage was channeling the lower ledges to ascertain its suitability for cut and sawed stone.

WARSAW.

THE PHILLIPS QUARRY.

This quarry, which is located one and a half miles north of town, in the S. W. ¼ of the N. W. ¼, sec. 8, T. 40 N., R. 22 W., is owned by C. B. Phillips and operated by J. S. Kidwell. It is situated near the crest of a hill and has a west face of about 135 feet. The stone is limestone of Burlington age. The following is a description of the beds from top to bottom:

1 ft.	Soil stripping.
3 ft. 6 in.	Buff colored, coarsely crystalline limestone. Splits into beds from two to six inches in thickness. It is badly broken by joints and is very fossiliferous.
10 in.	Gray to buff colored, fossiliferous limestone. This bed contains dries.
2 ft. 6 in.	Very coarsely crystalline, bluish gray, fossiliferous limestone. A suture joint one foot from the bottom, divides this bed into two layers. The stone has a buff color on both sides of the suture joint and for six or eight inches below the upper bedding plane.
1 ft.	Coarsely crystalline, bluish gray limestone. Buff colored along the bedding planes.
10 in.	Limestone similar to that above.

The major joints strike N. 70° W. Two other sets strike N. 21° E. and N. 55° W.

Most of the stone can be used either for foundations and ashler masonry or burned into a good grade of lime. It is used for both of these purposes, the output being sold chiefly to supply the local market.

WHITE HOUSE.

THE BUSSEN QUARRY.

This quarry, which is owned and operated by Mr. H. W. Bussen, is located one-fourth of a mile south of White House Station, on the St. Louis, Iron Mountain and Southern railroad. It is situated on a river bluff just west of the railroad tracks and has a face 110 feet long and about 40 feet high. It was opened in 1900.

The following is a description of the beds from top to bottom:

10 ft.	Gray to drab, finely crystalline limestone in layers from six inches to two feet in thickness. At the north end these layers have been removed by erosion.
3 ft. 4 in.	Fine grained, drab colored limestone. Splits along a bedding plane nine inches from the bottom. Joints occur along which the stone is colored buff.
1 ft. 6 in.	Yellowish gray limestone.
2 ft.	Dark gray limestone, merging above into a yellowish color. Beds show fine stratification planes.
2 ft. 3 in.	Fine grained, gray limestone.
6 ft.	Massive bed of fine grained, gray limestone. Contains dries.
3 ft. 10 in.	Argillaceous, drab colored limestone. Chert nodules occur at the top of the bed.
4 ft.	Very argillaceous, blue limestone, having a shaly structure. Upper portion contains small particles of pyrite.
5 ft. 9 in.	Yellow to buff colored semi-crystalline limestone. Shows white efflorescence on the surface. Two small layers of flint occur respectively three and fifteen inches from the top. Small flint nodules and large dark spots also occur in the stone.
6 ft. 4 in.	Fine grained, yellowish gray limestone. Small irregular nodules and layers of black flint occur from six to twelve inches apart. The upper six to twelve inches is very shaly and contains considerable chert.

2 ft. 2 in. Compact, light gray limestone, very brittle and breaks with a splintery fracture. Has dark stratification planes. Chert nodules occur along the bottom of the bed. The stone contains many dries.

8 ft. 6 in. Fine grained, gray limestone. Splits into three beds two feet, five feet and one foot in thickness. The stone is colored with iron oxide along the short tight seams, which occur throughout the bed. A layer of chert nodules occurs twelve inches from the bottom. Occasional chert nodules are also disseminated through the bed.

The entire output from this quarry is used for furnace flux in St. Louis.

CHAPTER IX.

PENNSYLVANIAN (COAL MEASURES.)

The stone in this system consists of both limestone and sandstone. It is found chiefly in the western and northern parts of the State. There are many quarries located in this formation, some of which are very large, as in the case of those at Warrensburg and Miami. In the previously described formations the most important quarries are in the limestone. In this, the largest quarries are in the sandstone.

This chapter is divided into two parts. The first contains a discussion of the limestone quarries, and the second, a discussion of the sandstone quarries.

AMAZONIA.

S. H. Atwood & Co., of Plattsmouth, Nebraska, have leased land on the farm of Jacob Schreier and have opened a quarry for crushing purposes, one mile north of Amazonia, just east of the Savannah branch of the Chicago, Burlington and Quincy railroad system. This quarry was opened in the spring of 1902 and has a face of 700 feet, along the west side of the bluff. The ledge, which is being quarried, consists of twenty feet of gray limestone, in beds from six to fourteen inches in thickness. It has an average stripping of two feet. Near the top a fourteen-inch bed of finely crystalline, compact limestone overlies three feet of yellow decomposed stone. Eleven feet from the base of the quarry is a heavy bed of limestone which is underlain by six inches of shale. The bedding planes are uneven and the beds are separated from one another by thin layers of shale. The stone is "shelly" and along the bedding planes it is somewhat disintegrated. Blasting breaks the stone into pieces sufficiently small so that comparatively little sledging is required before going to the crusher.

The stone is fine grained but contains geodes and fine seams of calcite. Where the quarry has been worked farthest into the hill the stone has a slightly bluish color. In some places it contains small flint nodules, which are not harmful for most purposes for which crushed stone is used. It spalls easily and breaks with a sharp fracture. The

quality of the stone improves and the beds become more solid as the quarry is worked into the hill.

The joints are irregular and strike mainly N. 35° E. and N. 21° W. Very little attention is given them in working the quarry.

At present the output is used mainly in the construction of concrete bridge abutments in railroad work.

The quarry is being worked eastward along a hill. The leased land includes the hill north of the present quarry, and it is the intention to fill the ravine between the two hills with stripping in order to operate two openings.

The crushing plant, which is one of the best in the State, is situated just west of the quarry. Two Gates crushers, a No. 3 and a No. 5, are being operated. The crushed rock is elevated and passed through a revolving screen, which separates it into a two-inch product and screenings. That which does not pass through the screen is returned to the small crusher over a belt conveyor and recrushed. The crushers and elevators are all operated from a line shaft. A locomotive boiler is used to furnish steam. The plant is so arranged that all parts of the machinery likely to need cleaning, adjustment or repairs can be reached easily and without danger. A gasoline engine and pump furnishes the plant with water. The rock is conveyed from the quarry to the crusher in extra large, heavy dump carts, which are drawn by two horses. The carts have a small third wheel in front which serves to relieve the team from the load. Substantial stables and houses have been erected by the company with a view of establishing a permanent plant. The initial cost of plant and buildings was $15,000. The land on which the quarry is located has been leased for fifteen years.

BETHANY.

Three limestone quarries, belonging respectively to W. H. Sperry, Gilbert Arney and R. L. Nelson, are operated in the vicinity of Bethany. They are located west and northwest of the city. At the Nelson and Sperry quarries the stripping is so heavy that it all but prohibits their operation. The Arney quarry has not as yet been worked far enough into the hill to have the full thickness of stripping. All the quarries are worked intermittently, supplying only the local demand for stone. The following are descriptions of them:

THE ARNEY QUARRY.

This quarry is located one mile northwest of Bethany, in the S. W. ¼ of the N. W. ¼ of sec. 10, T. 63, R. 28, and is owned by Gilbert

Arney. It has been opened along the southeast face for 100 feet. The following is a section from top to bottom:

3-6 ft.	Clay and dirt stripping.
1 ft.	Dark gray, fine grained limestone, containing occasional red spots caused by iron oxide. Chert nodules and a few small calcite geodes occur in this bed. Short dry seams are also present.
6 in.	Gray, finely crystalline limestone containing a small amount of iron oxide and chert.
1 ft. 3 in.	Dark gray, finely crystalline, fossiliferous limestone. Bed shows dry seams, nodules of chert, and some iron oxide.
1 ft. 4 in.	Very fossiliferous, gray, crystalline limestone. This bed shows a number of dry seams.

Two thick beds are quarried below this, but were not exposed when the quarry was visited. The joints are not very prominent. The two most important sets strike N. 20° W. and N. 68° E.

The quarry has been worked only along the outcrop. The beds are thick and the thin seams of shale which are common in this vicinity do not occur here. Most of the heavy beds show dries which are generally colored red or buff by iron oxide. The stone is quarried by using hand tools, and in this manner the heavier layers are quite difficult to handle. The greater part of the stone from this quarry could be used for heavy constructional work, such as bridge abutments, footing and foundations.

THE NELSON QUARRY.

This quarry, which is owned by R. L. Nelson, is located in the S. ½ of S. W. ¼, sec. 9, T. 63, R. 28 W., about a mile west of the Sperry quarry. It faces the north and has been opened eighty feet east and west. The following section shows the succession of beds from the top to the bottom:

6-10 ft.	Red clay stripping.
6 in.	Fine grained limestone, much broken.
3 ft.	Dark gray shale containing nodules of limestone.
6 in. 9 in.	Dark gray, fossiliferous crystalline limestone. Has a somewhat mottled appearance due to white spots.
8 in.	Dark gray, fossiliferous limestone. Dry seams occur in this bed.
7 in.	Gray, finely crystalline, very fossiliferous limestone.
12 in.	Similar to bed above. Has iron oxide along the bedding plane.

There are three prominent sets of joints, which strike N. 42° E., N. 54° E., and N. 57° W.

The beds separate readily and can be easily worked with plugs and feathers. The stone lies in beds of very convenient thickness for hand quarrying, dresses nicely, and has a very good appearance in a wall. The heavy stripping is troublesome.

The quarry has been rented in the past to parties desiring a few loads of stone and they have taken it out wherever it was most convenient, without regard to future work. In consequence considerable expense

will be necessary to put it in good condition. Had the quarry been opened near the bottom of the hill, the stripping could have been removed with less expense than at present, and the proportion of stripping to the amount of rock quarried would have been correspondingly less.

THE SPERRY QUARRY.

This quarry, owned and operated by W. H. Sperry, is located in the S. E. ¼of S. E. ¼, sec. 9, T. 63 N., R. 28 W., about three-fourths of a mile west of Bethany court house. It faces the west and has been opened about 700 feet north and south. The following section shows the succession of beds from the top to the bottom:

5-15 ft.	Gray shale and soil stripping.
1 ft. 7 in.	Heavy bed of dark gray, fossiliferous limestone. Will not stand frost when first quarried.
1 ft. 2 in.	Dark, fine grained, fossiliferous limestone. Will not stand frost.
10 in.	Similar stone.
4 ft. 10 in.	Soft, shelly stone. Bed is broken into small pieces but becomes somewhat more solid as it is worked into the hill.
5 ft.	Dark gray, finely crystalline, fossiliferous limestone, consisting of beds from four to eight inches in thickness, separated from one another by wavy bedding planes. The stone is slightly stained by iron oxide.
1 ft. 6 in.	Dark, finely crystalline limestone. Splits into two beds along uneven bedding planes.
1 ft. 10 in.	Dark bluish, fine grained limestone, containing layers of dark flint. Breaks very irregularly on blasting. Splits into four beds. Used for street work.

The principal joints observed strike N. 45° E. and N. 10° E.

The lower beds of the quarry have very irregular, wavy bedding planes and are mostly separated by very thin layers of clay. The stone in the bottom bed, although very compact, breaks so irregularly upon blasting that it can only be used for street paving and rough rubble work. The four foot ten inch bed disintegrates rapidly when exposed to the atmosphere. It is only used for street paving. The upper portion of the quarry consists of rather thick, solid beds. These should be quarried during the summer months, as they will not withstand the frost until seasoned. Hand tools are used in getting out the stone.

BIRMINGHAM.

THE SPRATLEY QUARRY.

This quarry, which is owned by J. W. Spratley and operated by Schriber & Sons, is located just northeast of the railroad depot. It has a south face about 600 feet long. The stone is obtained mainly from the upper ten feet of the Bethany Falls limestone. The stone in the upper four to six feet is a mottled dark and light gray limestone, which occurs only at the top of this ledge.

1.

2.

Fig. 1. Crushing plant, Breckenridge Stone Co., Breckenridge, Mo.
Fig. 2. Portion of quarry of the Breckenridge Stone Co., Breckenridge, Mo.

This quarry is equipped with a crushing plant and all of the stone is crushed for macadam and concrete. Plans for enlarging the plant and increasing the output were being made in 1902.

BRECKENRIDGE.

Messrs. J. W. Gibeaut and J. L. Amick lease quarry rights upon land owned by Mrs. Luetts Bush north of Breckenridge. Three openings have been worked on the east side of the road. The one farthest north is three-fourths of a mile from town. It has been opened about one hundred feet east and west along the south side of a hill. The following strata are exposed in the quarry from top to bottom:

2-3 ft.	Soil and broken stone stripping.
1 ft. 4 in.	Hard, crystalline, solid limestone, having a light bluish color. Bed contains pockets of bitumen. Upper portion buff colored.
1 ft. 8 in.	Gray, very porous, heavy bedded limestone. Will split with plugs and feathers but shows no bedding plane along which it will cap readily.
2 ft. 6 in.	Bed has capping seams 12, 18 and 24 inches from the bottom. Stone is porous and has a gray color.
1 ft. 8 in.	Bed caps ten inches from bottom along a stylolitic bedding plane. The bottom ten inches is very good gray stone similar to the 12 inch bed below.
1 ft.	Light gray, porous limestone, spotted in places with iron oxide. Bed works well.
1 ft. 7 in.	Gray, fine grained, slightly porous limestone. Has a bluish colored streak, two or more inches in thickness in the middle of the bed. Two stylolites occur near the top. There is an occasional colored dry seam. Can be split near the middle.

The stone is heavy bedded and works well. The 12-inch bed works better than most of the others. The beds gradually increase in porosity as the top of the quarry is approached, with the exception of the 16-inch bed which is very compact. The stone from all the beds, except the lowest, will stand frost. The major joints strike N. 40° W. The beds have a dip of 2° in the same direction.

The second opening is forty rods south of the one described above. This opening faces the west and extends about eighty feet north and south. The face is about eight feet high. The stone is very porous and contains pulverulent iron oxide, which fills small cavities in the stone. This washes out upon exposure to the atmosphere. The stone in the upper three feet of the quarry is very soft and porous, containing cavities which are often one-fourth of an inch wide by two or more inches long. Although the stone is soft, it is very hard to work. It does not spall readily. Where exposed to the weather it shows a rather smooth surface along the old outcrops. The stone from this opening does not work with the ease or regularity of that from the other two.

The largest opening lies south of the last and about one-half of a mile north of town. It faces the west and has been opened 150 feet north and south. The following is a description of the beds at this place from top to bottom:

2 ft.	Soil stripping.
6 in.	Hard, gray, crystalline limestone, containing occasional cavities.
3 ft.	Gray, porous, semi-crystalline soft limestone. Bed contains considerable pulverulent iron oxide in spots and streaks very similar to the upper layer, in the smaller opening. Bed splits well but spalls hard.
6 in.	Gray porous stone. Shows spots of oxide of iron.
9 in.	Very porous, gray limestone. Bed contains much iron oxide and has a somewhat sandy texture.
1 ft. 2 in.	Gray, porous limestone. Shows blotches of iron oxide.
9 in.	Similar stone.
10 in.	Gray, semi-crystalline limestone. Bed contains small spots of iron oxide.
1 ft.	Crystalline, bluish gray, compact limestone. Will not stand the frost.

The upper layers of this quarry contain a large amount of iron oxide in irregular cavities imparting to the stone a slight brownish color when quarried. Upon weathering the iron oxide washes out and leaves the surface somewhat pitted. This is especially the case with the three-foot bed. The stone becomes lighter in color as the iron is washed away. These cavities and spots become smaller and less frequent towards the base of the quarry, the lower ledge being quite free from them. Only hand tools, including a hand derrick, are used for moving the stone. The joints are prominent and strike N. 45° E. The beds dip about 3° to the north.

These quarries can produce a very durable building stone and one which is especially well adapted for bridge abutments. The stone can be split into rectangular blocks of any required dimensions and with the exception of one bed is not affected by frost. The lower beds are of a pleasing gray color and contain very little iron oxide. The stone in the upper beds contains too much iron oxide to give it a pleasing appearance.

These quarries have been opened only recently. A large quarry just south of the opening last described was opened in 1891 by Mr. Gibeaut. This was worked for some time, but has not been active for a number of years. The stone is very similar to that which occurs in the quarries described.

The stone has been used locally for foundation work and has also been shipped to St. Joseph.

In 1903, since this quarry was visited, the Breckenridge Stone Company was organized to operate the quarry opened by Mr. Gibeaut. This company is incorporated for $10,000 and the following are the

officers: O. J. Chapman, president; J. W. Rozzle, secretary; J. W. Gibeaut, superintendent. A side track has been built connecting the quarry with the Hannibal and St. Joseph railroad and a crushing plant has been installed. The company intends to operate it much more extensively than it has been in the past.

LABORATORY EXAMINATION.

Chemical Analysis.—The following chemical analysis shows the stone to be almost pure calcium carbonate, there being little over 3 per cent. of impurities:

Insoluble	2.93
Fe_2O_3, Al_2O_3	.54
CaO	54.22
MgO	.22
CO_2	42.58
Total	100.49

Physical Tests.—The limestone has the following physical properties:

Specific Gravity	2.454
Porosity	8.185 per cent.
Ratio of Absorption	3.944
Weight per cubic foot	141.2 pounds.

The tensile strength of the stone is 565 pounds per square inch; the crushing strength averages 6,944.5 pounds per square inch on bed and 8,035.5 pounds per square inch on edge. Two samples were tested on bed and two on edge. One of the samples on bed gave a very low test, bringing down the average. The highest test was 8,274 pounds per square inch. The transverse strength is 1,341.46 pounds per square inch.

Samples which were subjected to the freezing and thawing test lost .078 per cent. in weight. The crushing strength of the sample which was subjected to the freezing test was 8,163 pounds per square inch. This test shows that the stone is not affected materially by alternate freezing and thawing.

BROOKFIELD.

Three small quarries are operated at Brookfield, known respectively as the Bottomly, McClintock and Morris. They are located east and southeast of the city. The stone in all these quarries is obtained from the same ledge and, in general, the character of the stone is the same.

THE BOTTOMLY QUARRY.

This quarry, which is located two miles east of town, in the S. W. ¼ of N. W. ¼, sec. 4, T. 57, R. 19 W., is owned and operated by J. C.

Bottomly. The beds in which it has been opened are near the base of the north side of the hill. It is operated only when there is a local demand for stone. When inspected, the quarry was entirely covered with sand and soil which had washed into it during the spring. The stone is removed with a hand derrick and worked entirely with hand tools.

The stone is used for foundations, coursing, caps and sills. The rough stone is sold for one dollar and fifty cents per perch in Brookfield. The output in 1900 was 300 perch and in 1901, 200 perch. This quarry was not operated during 1903.

THE McCLINTOCK QUARRY.

This quarry, which is located two and one-half miles southeast of Brookfield, in the S. W. ¼, sec. 9, T. 57, R. 19 W., is owned by James McClintock and is operated by John and Ed. McClintock. It has been worked intermittently since 1870. During this period the ledge has been quarried nearly one-fourth of a mile north and south along the outcrop. and into the hill from 50 to 100 feet.

The quarry face consists of one ledge of limestone varying in thickness from twenty-two to twenty-six inches. This ledge consists of two beds, the upper being from fourteen to eighteen inches and the lower eight inches thick. The two beds are very much alike and consist of dark blue, compact, fine grained, fossiliferous limestone. This stone works well with plugs and feathers, breaking with a very smooth, straight fracture. It works nicely into steps, sills, caps and coursing. The major joints strike N. 45° E. The limestone ledge is overlain with eleven feet of blue shale at the place where the quarry is being developed. This ledge is also underlain with shale. Only about twenty feet of the face of the quarry is now being worked. A hand derrick is used for moving the stone.

THE MORRIS QUARRY.

This quarry is located two miles east of town. It is owned by Madison Morris and operated by J. W. Morris. It is situated in a valley and consists of an irregular shallow opening covering about three-fourths of an acre. It is so situated that it fills with water, seriously hindering quarrying operations. The same ledge of limestone is worked as at the previously described quarries. The major joints strike N. 45° E. and are from two to four feet apart, greatly facilitating the quarrying. The annual output during the last two years has been about 300 perch.

BUTLER.

Two quarries are operated in the vicinity of Butler. One is a small limestone quarry owned and operated by John Trimble, and the other is a sandstone quarry owned and operated by J. T. Day.* All the stone from both quarries is used locally.

THE TRIMBLE QUARRY.

This quarry is located in the southwestern part of the city. The face extends north and south from Ft. Scott street to Dakota street and has a depth of from six to eight feet. The stone belongs to the Lower Coal Measures.

The following section shows the character of the stone now being quarried at the north end:

1 to 3 ft.	Stripping.
7 ft.	Dark and light gray, fine grained fossiliferous limestone. Splits into beds from two to eight inches in thickness. Bedding planes rough and wavy. The uppermost eight inch bed is solid fine grained limestone. The remainder is shelly and suitable only for macadam or very rough foundations.
1 ft. 1 in.	Bluish, fine grained limestone. Weathered to a buff color along the bedding planes. This is the best stone in the quarry.
1 ft. 8 in.	Fine grained, compact, blue limestone. Splits into two ten inch layers. Now forms the floor to most of the quarry.

The major joints strike N. 50° E.

The stone is used for curbing, foundations and sidewalks. A small amount of the stone has been broken by hand and used to macadamize the city streets.

This quarry must be abandoned soon unless additional land is acquired.

EAST LYNNE.

A quarry which is owned by Paul Schindorf is located three and one-half miles north of East Lynne. It was opened about thirty years ago, but has not been operated for a number of years.

It is situated on a hill and has been operated along the outcrop on the north, south and west sides. The stripping consists of about five feet of shale. Underneath this is a single bed of compact, crystalline, fossiliferous, dark gray limestone from eight to ten inches in thickness. The stone breaks with a straight fracture when worked with plugs and

*For description of this quarry see under Sandstone Quarries.

feathers and can be quarried in pieces from twelve to twenty feet long. It is very durable and makes excellent steps, sills, coursing, etc. The amount of stripping and the very limited demand has resulted in the quarry being abandoned.

GALLATIN.

Three quarries, known as the Cubberly, the Walker and the Brosins, have been opened in the vicinity of this city. They are in limestone of Pennsylvanian or Upper Carboniferous age. The quality of the stone is essentially the same in all these quarries.

THE CUBBERLY QUARRY.

The quarry owned and operated by Albert Cubberly is located in the outskirts of the city, just south of the Chicago, Rock Island and Pacific railroad. It was opened six years ago and has been worked intermittently to supply the local demands. It is on the east side of the hill and consists of two openings, one above the other, separated by a soil covered slope. The faces at the two openings expose the following succession of strata:

Upper opening:

0-1 ft.	Dirt stripping.
1-3 ft.	Limestone broken into about two inch pieces. Called "Natural Macadam."
6 in.	Very fine grained, light colored limestone. Spalls hard.
8 in.	Similar rock but not so difficult to work.
6 in.	Finely crystalline, light gray limestone.
7 in.	Fossiliferous, fine grained, light gray limestone.
10 in.	Gray, fossiliferous, medium textured limestone.
7 in.	Dark gray limestone, dresses easily. Top portion shelly; not injured by frost.

Lower opening:

2-5 ft.	Yellow clay and broken stone stripping.
2 ft. 8 in.	Dark gray, fossiliferous limestone; buff colored along bedding planes. Can be split into beds six inches in thickness.
1 ft.	Gray shale.
2 ft.	Dark, compact, fossiliferous limestone. Weathered to a brownish color along bedding planes

Two prominent sets of joints in the lower beds strike N. 40° E. and N. 40° W. These joints are from three to four feet apart, breaking the stone into nearly cubical blocks.

The thickness of the clay stripping and the difficulty experienced in separating the beds makes the stone in the lower opening more expensive to quarry than that in the upper. For this reason the upper opening is being worked at present.

The beds in this opening are uniform in thickness and dress readily into caps, sills and coursing. The upper beds spall and work hard, while

the lower ones dress with little difficulty. The waste stone is broken by hand and used for macadam. Only hand tools are used.

THE WALKER QUARRY.

This quarry is located near the eastern limits of the city and is owned and operated by Sam. Walker. It was opened in 1897 on a four-acre tract of land. The face is irregular and about 600 feet long. At the time the quarry was examined there was exposed 3ft. 4 in. of bluish finely crystalline, fossiliferous limestone in beds from six to eight inches in thickness. These beds are blue in the interior and buff on the exterior. They are separated from one another by thin clayey seams. Six feet of yellow and red clay stripping occurs above this bed. Five beds from six inches to one foot in thickness are worked below that which is exposed.

The joints strike N. 45° E. and N. 60° W. The stone is used for foundations, wells, and macadam. Two car loads of crushed stone, broken by hand, have been shipped to Chillicothe. It is sold for $2.50 a yard F. O. B. Gallatin.

THE BROSINS QUARRY.

The quarry owned by Samuel T. Brosins was opened in 1886 along the railroad east of the Cubberly quarry. It is located in the S. W. ¼ of N. E. ¼, sec. 17, T. 59, R. 27 W. The stone is blue and gray limestone, very similar to that in the other quarries of Gallatin.

The stone from this quarry has been used by the Chicago, Rock Island and Pacific railroad to build bridge abutments and retaining walls. It is suitable for breakwater, foundations, bridge abutments, curbing and retaining walls. The quarry has been idle for a number of years.

HAMILTON.

Two small quarries, known as the Rogers and the Stock, have been opened northeast of this city. They are situated at different horizons in the Upper Coal Measure strata.

THE ROGERS QUARRY.

This quarry, which is located one and one-half miles northeast ot the city, is owned by Geo. Rogers and operated by John Yeager. The quarry has about three feet of soil stripping which is being removed for about 50 feet along the face. The marketable stone consists of a one to two-foot bed of limestone which is immediately underneath the soil. The stone has a grayish color and is fossiliferous and finely crystalline. It is underlain with shale. The stone is used locally for foundations.

THE STOCK QUARRY.

This quarry is located four miles northeast of Hamilton and is owned by John Stock. It is operated intermittently by John Yeager. It is situated on the south slope of a hill and has been opened 115 feet east and west. The marketable stone consists of a fifteen-inch ledge of dark blue, compact, fossiliferous limestone, which is covered with from two to three feet of stripping. It has a fine grained groundmass through which are scattered large individuals of calcite.

The joints are very prominent and are of assistance in quarrying. They strike N. 40°-50° E. and are from six to ten feet apart.

The stone breaks well with plugs and feathers. It has every appearance of being durable. It has a uniform thickness and color making excellent ashler blocks. It is also suitable for steps, caps, sills, etc. One derrick and hand tools are used in quarrying and working the stone.

HARRISONVILLE.

Two quarries have been operated at Harrisonville, the stone being used exclusively for local consumption. One of these is owned and operated by John Lee, and the other by A. Conger. The stone is of Upper Coal Measure age and is very much alike in both quarries.

THE CONGER QUARRY.

This quarry, which is located near the eastern limits of the city, is not being operated at present. It has a six-foot face, consisting of beds of fossiliferous limestone from two to ten inches thick. The stone is partly decomposed along the bedding planes. The principal joints strike N. 50° E. The quarry has been operated mainly to produce broken stone for macadamizing the streets of Harrisonville.

THE LEE QUARRY.

This quarry has been opened 300 feet north and south and 175 feet east and west along the crest of a gently sloping hill. It has a ten-foot face, composed of beds of fine grained, compact, gray limestone varying in thickness from two to fourteen inches, and separated from one another by thin seams of shale. The stripping consists of from one to three feet of clayey soil. The bedding planes are irregular and wavy. The stone contains dry seams along which it has been colored yellowish brown with iron oxide. Some of the layers show roundish or irregular dark spots, which give the stone a somewhat mottled appearance.

The major joints strike N. 50° E. and N. 45° W. They are from

twenty to thirty feet apart and frequently, near the surface, they are opened and filled with clay.

Hand tools are used in quarrying and working the stone. Most of it is marketed in irregular blocks suitable only for rough masonry. Some of the thinner beds, although they have very rough, irregular surfaces, have been used for sidewalks.

HIGGINSVILLE.

Two quarries have been opened south of Higginsville, neither of which was being worked when inspected. They are owned by the August Hoefer estate and Mr. Leslie McMeekin of Warrensburg. Neither quarry has been worked extensively.

THE HOEFER QUARRY.

This quarry is located one and one-fourth miles southeast of Higginsville, in the N. E. ¼ of sec. 7, T. 49, R. 26 W. When visited it had been idle for some time and the soil from above had washed over the face covering the lower beds. The rock is typical Lower Coal Measure limestone. The two lower beds are the thickest, being ten and fourteen inches resepectively. The other beds are from two to six inches thick and are separated from one another by irregular wavy bedding planes. The limestone is compact, fine grained and fossiliferous. The color is blue, although along the bedding planes and joints it has been altered to a buff, in some places to a depth of five or six inches. The thick beds do not work well owing to small dry seams which are colored with iron.

The joints strike N. 40° E. and N. and S. They are from six to ten feet apart and are very important aids in quarrying. When the quarry was first opened, the beds were easily separated by a crowbar and broken into irregular blocks by sledges. As the work was carried farther into the hill the beds became thicker and some blasting was required to break the stone. It is used for foundations and to some extent, in Higginsville. for macadam.

THE McMEEKIN QUARRY.

The quarry owned by Mr. Leslie McMeekin is located two and one-half miles southwest of the city. The opening is 100 feet long. When inspected the face was entirely covered with stripping which had washed over it since the quarry was last workd. The face consists of three workable beds, six, ten and twelve inches thick. Between the two latter beds, occur from ten to eighteen inches of worthless shelly stone.

The stone is a very compact, dark blue, semi-crystalline limestone. which works well under the chisel and breaks with an even fracture.

INDEPENDENCE.

Two quarries, known as the Shaw and the Turner, are operated in the vicinity of this city. The Turner quarry supplies the local demand for building stone. The Shaw quarry is being (1902) operated to supply crushed stone used for macadam on the county roads.

THE SHAW QUARRY.

Mr. Geo. W. Shaw of 101 E. Pacific street, Independence, has opened a quarry two and one-half miles southwest of Independence on the Braytown road. This quarry, which is situated at the base of a hill, is 350 feet long and has a vertical face of eighteen feet.

The lower four and one-half feet is compact, finely crystalline, fossiliferous limestone, which contains small irregular veins of calcite and dries. A nine-inch bed above these is very fossiliferous. With the exception of the upper three feet, the remainder of the face consists of two to ten-inch beds of dark gray, fine grained limestone. The upper three feet consists of eight to ten-inch beds of black, very fine grained limestone. These beds are underlain with a layer of flint nodules which are partially decomposed and soft. Three feet of rather hard calcareous shale, which overlies the limestone, is used for bonding the crushed limestone used for macadam. The beds, which vary in thickness in different parts of the quarry, are covered with four feet of clay stripping.

The quarry is equipped with a crushing plant, consisting of a No. 4 Gates crusher, bucket elevator, 40-horse power boiler, and a 35-horse power engine. The product is entirely crushed stone, which is used for macadam. Thirty to thirty-five teams are required to haul the stone to and from the crusher.

THE TURNER QUARRY.

This quarry, which is owned and operated by Mr. W. R. J. Turner, is located one and one-half miles east of Independence. It consists of three openings, only one of which is being worked at the present time. The rock in the largest opening is limestone belonging to the Bethany Falls formation and has the same general characteristics as that at Sheffield and Kansas City.

The largest opening is situated just north of the road and has a vertical face of about twenty feet. The following is a description of the beds from top to bottom:

0-4 ft.	Clay stripping.
11 ft.	Dark gray mottled limestone. The upper four feet contains very thin seams of shale along which the stone splits very readily. The stone from these beds weathers into small nodules from the size of a pea to that of a walnut.
2 ft. 4 in.	Four beds which are a transition between the mottled limestone above and the light gray below. It is fine grained and compact.
1 ft. 2 in.	Light gray, fine grained, compact limestone.
6 in.	Shelly limestone.
1 ft. -1 ft. 4 in.	Fine grained, gray, fossiliferous limestone. The stone is stained yellow along short dry seams.
6 ft.	Thinly bedded limestone containing thin seams of shale. The rock is fine grained and fossiliferous and has a dark gray color.

The second opening is situated on the hillside above the one just described. The face is 120 feet long and 12 feet high. The stripping consists of from two to five feet of clay. The upper eight feet of the quarry consists of four to six-inch beds of fine grained, bluish gray limestone, having irregular wavy bedding planes. The three feet immediately underneath these beds consist of four to five-inch beds of bluish gray limestone. Underneath this is a twelve-inch bed of the same kind of stone. Everywhere along the bedding planes the color of the stone has been altered to a buff and is known as "yellow rock."

Across the valley, northeast of the second opening, is a third small opening which has not been worked to any extent.

The second is the only opening now being worked, and the stone is used almost exclusively for rubble work. Formerly the larger opening was operated extensively for macadam.

JAMESON.

Two quarries, known respectively as the George and the Prichard, are located near this village. The rock is limestone and belongs to the Pennsylvanian or Upper Carboniferous system.

THE GEORGE QUARRY.

This quarry, which is owned and operated by Mr. A. B. George, is located about three miles southeast of Jameson. It was opened December 1, 1901, and is worked continuously. The face is 1,850 feet long and averages about 30 feet in height. The following is a section from top to bottom taken from the north central portion of the quarry:

1-5 ft.	Broken stone and soil. Stripping.
6 ft.	Light gray limestone. Beds are from six to twelve inches in thickness, the heavier of which could be used for constructional purposes.
5 ft.	Limestone in beds from two to six inches in thickness.
2 ft. 4 in.	Yellow clay.

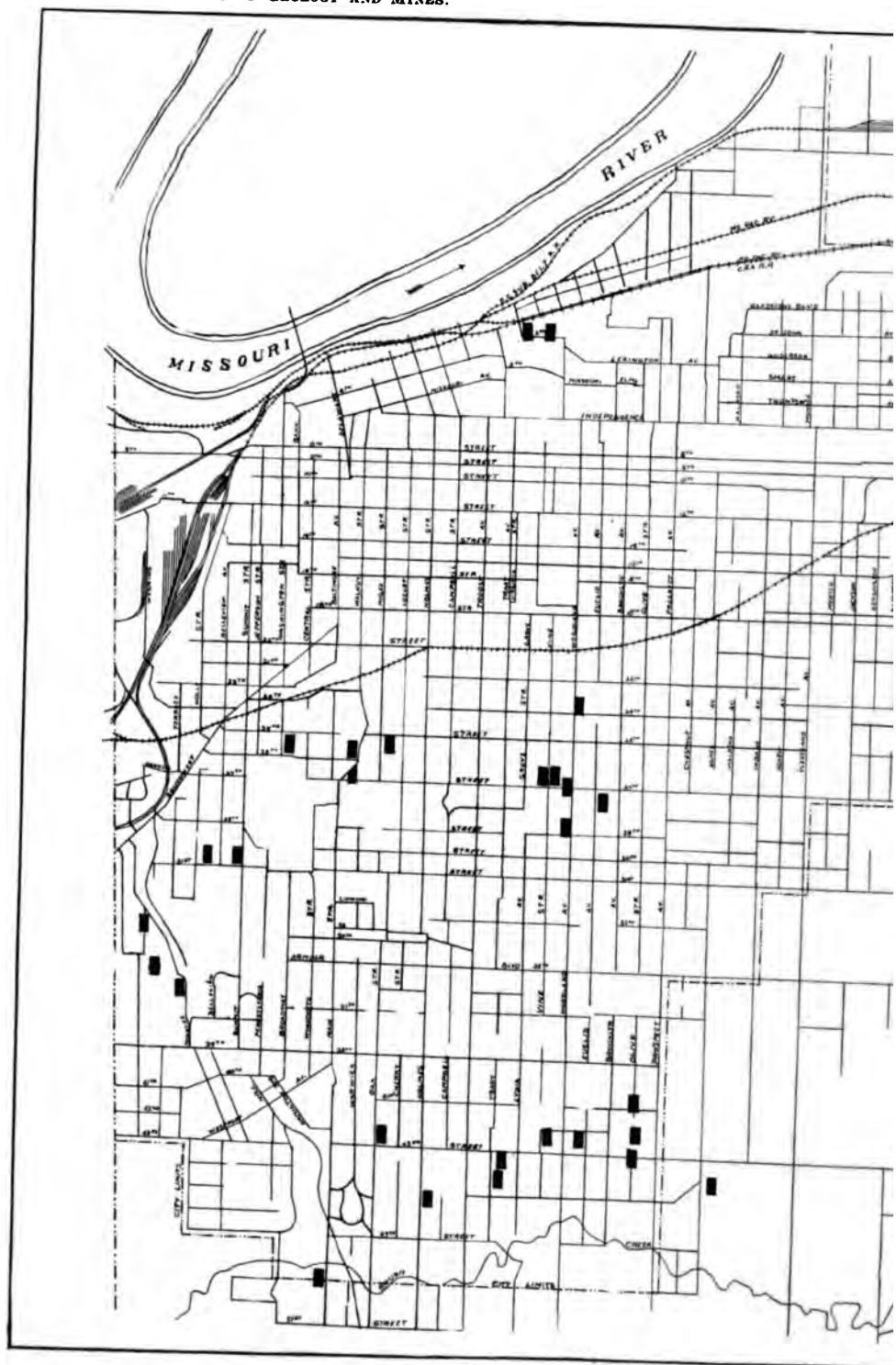
1 ft.	6 in.	Fine grained, compact, dark, fossiliferous limestone. Can be split into three beds.
2 ft.	5 in.	Dark colored shale.
2 ft.		Bluish gray, finely crystalline limestone. Can be split into three beds from six to eight inches in thickness. Between these beds occur seams of shale from one to two inches in thickness.
5 ft.		Fine grained, dark colored limestone. Splits into ten or twelve beds about six inches in thickness. Stone contains geodes of calcite.
2 ft.	4 in.	Dark colored, finely crystalline limestone. Slightly buff colored in places due to the occurrence of iron oxide.

The two major sets of joints strike N. 70° W. and N. 20° E. Two minor sets strike N. 55° W. and N. 30° E. The major joints are open and usually occur from six to twenty feet apart. They are of considerable assistance in quarrying.

The quarry is equipped with a Gates crusher No. 7, a Buckeye automatic engine, two portable boilers, a 50-foot bucket elevator, a 12-foot screen, and 40 dump cars. The crusher is situated near the middle of the quarry. The entire face is being worked and tracks have been laid in both directions from the crushing plant.

The cars are drawn by horses. The stone from the quarry is dumped into a chute by which it is carried directly to the crusher. From the crusher it is elevated to the revolving screen, by which the product is separated into two sizes, known as screenings and 2-inch ballast. The stone is dropped from the screens into bins, from which it is drawn directly into the cars.

The method of operating this quarry is different from that employed at any other in this state. Each quarryman is allotted fifteen feet of quarry front, known as his "quarry," to which portion he is supposed to confine his work. Two or more men may combine and work in cooperation. Each man is paid 25 cents per dump car of rock loaded at his quarry. The operator furnishes the empty cars and removes the loaded ones. Each man does his own stripping. A plank, extending from the face and supported at one end on the top of the quarry and at the other by cross timbers, serves as a track over which to wheel the stripping and carry it some distance beyond the quarry face. By this method, the work of stripping does not interfere at any time with the quarrying. Checks, hung upon the cars, are used to keep a record of the number of loads and by whom they are delivered. The men are given credit for cars as they are delivered at the crusher. In this way each man is paid according to the amount of work which he does. They earn from $1.00 to $4.50 per day. The output amounts to from twenty to twenty-two cars of crushed rock per day. In 1902 the stone was being used by the Wabash railroad for ballast between Pattonsburg and Omaha, Nebraska.



Map of Kansas City showing location of quar

THE PRICHARD QUARRY.

This quarry is located one mile south of Jameson in the N. W. ¼ of the S. W. ¼, sec. 19, T. 60, R. 27 W., and is owned by Mrs. Ruth Prichard of Gallatin.

It consists of from one to three feet of red clay stripping, two feet of dark blue shale containing a four-inch layer of broken limestone, an eight-inch bed of blue, fine grained, fossiliferous limestone and seven and ten-inch beds of finely crystalline, blue to dark colored limestone. Along the bedding planes, the stone has been weathered to a buff color.

This quarry was opened in 1883 and has been worked intermittently since that time. The output has been used almost exclusively for foundations.

KAHOKA.*

THE FULTON & CREGER QUARRY.

This quarry is located in the S. W. ¼ of sec. 9, T. 65, R. 7 W. It is situated at the top of a bluff on the south side of the Fox river and has a face 60 feet long. The stone consists of a three foot six-inch bed of gray limestone, a one-foot bed of shelly limestone and four feet five inches of dark colored limestone. The uppermost bed breaks into small polygonal blocks, while that below has numerous bedding planes, along which it can be split into thin layers, none of which exceed eight inches in thickness. The quarry is covered with from six to eight feet of clay.

KANSAS CITY.

The hilly character of Kansas City and her environs gives rise to many outcrops of rock with a correspondingly large number of quarries. In 1902, when the quarries in this locality were examined, there were thirty-two in operation, all or part of the year.

The stone in all the quarries belongs to the lower beds of the Upper Coal Measures. The formation at this horizon consists of beds of limestone and shale of variable thicknesses. The rock is everywhere overlain with from one to forty feet of till and loess belonging to the glacial period.

The following columnar section, furnished by Mr. S. J. Hare, of Kansas City, gives the average thickness of the beds which outcrop in this locality:

0-40 ft.	Loess and till. A fine grained, yellowish, sandy clay.
11 ft.	Gray limestone.
1 ft.	Calcareous sandstone.

*See under Sandstone, part II of this chapter.

5 ft.		Sandy shale.
2 ft.		Conglomerate.
14 ft.		Shaly sandstone.
21 ft.		Sandstone and shale.
1 ft.		Ferruginous conglomerate.
3 ft.		Shale.
4 ft.		Limestone.
6 ft.		Sandy shale. (The section to this point was not examined, owing to the fact that it was in a large measure covered by buildings, etc. None of the stone above this horizon has been quarried.)
30 ft.		Fine grained limestone. Contains numerous geodes and small irregular veins of calcite. It consists of irregular beds which increase in thickness from the top to the bottom. These beds are exposed along the west bluff, 7th street to 24th street, along the east bluff from Garfield avenue to the eastern limits of the city, at 24th and Locust streets, at 27th street and Grand avenue, and at 3030 Summit street.
21 ft.		Blue shale. These beds are exposed at 27th street and Woodland avenue, 20th street and Woodland avenue, 23rd street and Fairmont avenue, 7th street and Walnut, 10th street and Baltimore avenue, 12th street and West bluff, North bluff, Garfield avenue east and 27th street and Grand avenue.
6 ft.		Fine grained, compact limestone having a variegated color, known locally as the "calico" ledge. Outcrops along West bluff, East bluff, and 27th street and Grand avenue.
13 ft.		Red and yellow shale. At the quarry of the Lyle Rock Co., these shales are only eight feet thick.
9 ft.	6 in.	Known as the "building ledge." Consists of seven feet of thinly bedded, fine grained, gray limestone, underlain with a solid bed of light blue, fine grained limestone two feet six inches in thickness. Above this heavy bed the stone is very thinly bedded and shelly, and in most of the quarries has a yellowish or buff color due to weathering. The limestone at this horizon outcrops at the following places: 25th and Vine, 24th and Locust, 45th and Charlotte, 49th and Main, and 36th street and Roanoke Boulevard.
4 ft.		Bluish black shale.
4 ft.		Yellowish, calcareous shale. Has somewhat the appearance of yellow ochre.
11-12 ft.		Coarse grained, very fossiliferous, gray to brown, oölitic limestone. Shows cross-bedding in the outcrop at the S. W. corner of 6th street and West Bluff. This bed splits easily along the stratification planes and makes very good rubble. It is quarried at the Lyle Rock Co. and the Johnson quarries. It is considered one of the most durable stones in Kansas City, although, when laid on edge it is liable to split along the bed. It outcrops at the following localities: 6th street and Bluffs; 12 street and Bluffs; Elmwood and North Bluff; and 2nd and Lexington.
1 ft.	6 in.	Blue shale. Outcrops at the Johnson and the Lyle Rock Co. quarries. At the latter quarry, it is only one inch thick.
6 ft.	6 in.	Solid, fine grained fossiliferous limestone. Contains small geodes and veins of calcite. Known, locally, as the "Bull ledge" because of the difficulty in working it. The stone has a gray color except along the bedding planes, where it is buff. These beds outcrop at the following places: 2nd and Lexington and along North Bluff.
15 ft.		Dark colored shale. Outcrops at the same places as the ledge above.
12 ft.		Dark shale interstratified with thin beds of limestone. Outcrops at same localities as shale immediately above.
	4 in.	Coal. Outcrops when visited were concealed by talus.

16 ft.	5 in.	Fine grained, siliceous, bluish gray limestone. Contains irregular nodules of black chert, mainly near the top. These beds outcrop along the "West" bluff and at the base of the bluff near the Lyle Rock Company's quarry.
5 ft.		Thin interstratified beds of shale and limestone.
3 ft.	6 in.	Fine grained limestone.
	6 in.	Shale.
2 ft.	6 in.	Fine grained limestone.
	6 in.	Shale.
5 ft.	6 in.	Fine grained, bluish gray to drab limestone.
5 ft.		Shale. Color varies from a yellow to a dark brown. Outcrops at 20th and Southwest Boulevard.
4 ft.		Nodular and shelly limestone above the Bethany Falls. Outcrops at 24th and Fairmont streets.
18 ft.		Heavily bedded Bethany Falls limestone. The upper six feet is mottled, while the remaining lower portion has a uniform grayish color and is finely crystalline. Outcrops at 29th street and Southwest Boulevard; at the waters edge near the Missouri river bridge; and in the Sheffield quarries. The upper portion decomposes quite readily upon exposures to the atmosphere.
5 ft.		Dark colored, thinly bedded shale. Outcrops just west of the railroad near Southwest Boulevard.

The beds in the quarries are practically horizontal. The major joints strike N. 45° E. and N. 45° W. They are persistent throughout the entire district and occur from seven to twenty feet apart. Frequently they are open and filled with red clay. They facilitate very greatly the quarrying operations.

Hand tools are used almost entirely in quarrying. Most of the crushing plants which have been erected are modern in all respects. Most of the quarries are operated intermittently, depending upon the demand for stone. The cost of quarrying in some places is increased very greatly by a heavy stripping of loess.

The Bethany Falls limestone was at one time used quite extensively for macadam. At present, however, it is only being exploited at the Sheffield quarries where the product is rubble. The oölitic bed and the so-called "Bull ledge," occurring below, are the lowest in the section that are being used to any extent for building. These ledges are being worked mainly in the quarries in the north part of the city. Commercially, the nine foot six inch limestone ledge, known as the "building ledge," is the most important. This is quarried in nearly all sections of the city where building stone is produced. In the past the lower two and one-half feet of this ledge has been used for curbing. However, the stratification planes, which are scarcely noticeable in the freshly quarried stone, make it unfit for this purpose. An examination of the curbing which has been in use a comparatively short time, shows the undesirable nature of this stone. At present it is only used for repairing curbing already laid. Most of the stone used for foundations and rustic masonry comes from the thin

yellow layers above this bed. The reddish and yellowish gray colors recommend it for rustic masonry. Many houses in Kansas City are now being constructed entirely out of this stone. The so-called "calico" ledge, owing to its hardness and limited occurrence, is not quarried very extensively. This is perhaps the best limestone for macadam pavements which can be obtained from the quarries in the vicinity of Kansas City. The thirty-foot ledge of limestone outcrops at many of the higher points throughout the city, especially along the West bluff, just east of the Union depot. Some good building stone and heavy footing can be obtained from the lower beds, although the stone is at present used mainly for crushing.

The following are short descriptions of the individual quarries of Kansas City and vicinity:

THE CLARK QUARRY.

This quarry is situated in a ravine east of 42nd street and Michigan avenue. It is owned and operated by Mr. A. M. Clark of 35th street and Prospect avenue. The face of the quarry is 160 feet long and from eight to sixteen feet high. The following section shows the thickness of the beds and the character of the stone:

2-10 ft.	Clay and shale. Stripping.
2 ft. 6 in.	Heavy bed of rather soft fossiliferous, gray limestone. Has a semi-oölitic texture. The bed splits and works well.
3 ft.	Fine grained, compact, gray limestone. Contains short tight seams, known as dries. Nodules and thin veins of calcite occur throughout the bed. Very fossiliferous.

The stone in the upper bed works well into sills, caps and coursing. The stone in the lower bed is not so satisfactory for these purposes. The major joints strike N. 40-50° E. Another set strikes N. 40° W. This quarry was not operated in 1903.

THE COLYER BROS. QUARRIES.

Colyer Bros. (Daniel and Kit) of Independence, Missouri, are operating three quarries near Kansas City. The product is almost exclusively crushed stone for concrete, macadam and railroad ballast. They move their crushing plants from one quarry to another in filling contracts for macadamizing county roads. The crushers located at 27th and Grand avenue and south of Sheffield are permanent.

One of the quarries, which was being operated in 1902, was located at the junction of 59th and Main streets. It has a west face 500 feet long and eleven to seventeen feet high. The following is a section of this face showing the thickness and character of the different beds:

4-10 ft.	Clay stripping.
1 ft. 6 in.	Fine grained, bluish gray limestone. A good stone for building.
4 in.	Grayish limestone.

3 ft.	8 in.	Compact, fine grained limestone. Dark gray patches give it a mottled appearance. The stone is brittle, breaking with a sharp fracture. Splits into two beds, 20 and 24 inches in thickness.
2 ft.		Fine grained, brittle bluish limestone. Undesirable as a building stone, but a good quality of limestone for macadam.

This horizon is what is known as the "calico" ledge in the generalized section.

At the south end of the quarry, the beds dip slightly to the south.

The quarry is equipped with a No. 4 Gates crusher, a bucket elevator and screens, all of which are operated by a 50-horse power engine. The stone is separated into two sizes, two inch and screenings. This plant employs forty-five men.

The second quarry operated by this company is located on the east side of the Blue river valley, south of Sheffield. It is situated south of 27th street, just east of the Kansas City Southern railroad. The stone is crushed exclusively for railroad ballast.

The quarry has a west face 425 feet long and seventeen feet high. The stone belongs to the Bethany Falls limestone formation. It is essentially the same as at Sheffield with the exception that the upper beds contain considerable brown iron oxide, filling small cavities. When blasted, it breaks into rather thick blocks. Owing to its somewhat spongy nature, part of it does not break readily with sledges.

The major joints strike N. 30° E. and N. 45° W. They are usually open from six to eight inches at the surface and filled with red clay.

This plant is equipped with a No. 6 Gates crusher, bucket elevator, screen, engine and boiler. The daily output is about 400 cubic yards of one and one-half inch stone and screenings. An average of from fifty-five to sixty men are employed at this plant.

The third quarry operated by this company is located at Grand avenue between 26th and 27th streets. Openings have been made on both sides of the avenue, but, at the present time, quarrying is being carried on only at the east side. This quarry has been in operation three years. The east opening has a face 300 feet long and a maximum height of thirty feet. The bottom three feet are being left for rubble stone. This stone is fine grained and has a blue color, being very suitable for rubble work. Immediately above this ledge, the stone consists of heavy beds which are used for heavy footing and rubble, when there is a demand for such stone. The following section gives the thickness and uses of the five lowest beds:

2 ft.	2 in.	Footing.
	10 in.	Rubble.
	14 in.	Rubble.
	18 in.	Rubble.
3 ft.		Footing.

The beds which occur above these are used exclusively for the manufacture of crushed stone.

The major joints strike N. 45° E. Another less prominent set strikes N. 40-50° W. This plant is equipped with a No. 4 Gates crusher, bucket elevator, screen, engine and boiler. The plant employs thirty-five men and has a capacity of 200 cubic yards of crushed rock per day. The output is used chiefly for concrete and macadam in Kansas City.

THE EDWARD CREBO AND COMPANY'S QUARRY.

The quarry of Edward Crebo and Co. is located a half mile south of Leeds on the east side of the Missouri Pacific railroad. When visited, it was just being opened and the ground cleared to install a crushing plant. The entire output is to be used for railroad ballast and concrete work.

The quarry is situated on an east and west ridge which is about 225 feet in breadth. The beds are the lowest quarried in the vicinity of Kansas City. The following section gives the succession of strata from top to bottom:

0-1 ft.	Stripping.
6 ft.	Lower portion of Bethany Falls limestone.
3 ft.	Dark shale.
1 ft. 1 in.	Fine grained, dark limestone.
4 ft.	Clay.
13 ft.	Fine grained, dark gray beds of limestone from two to thirty inches thick, separated by thin beds of shale along rather irregular bedding planes. The lower beds are from two to two and one-half feet thick.

The lower is the most important ledge. The overlying shale beds cause rather expensive stripping. The quarry was in operation during 1903 and produced a large quantity of crushed stone.

THE EAGLE CONTRACTING CO.'S QUARRY.

Mr. Adam Armstrong of Kansas City, Kansas, owns and operates a quarry at 3030 Summit street, under the firm name of "The Eagle Contracting Co." The quarry is located on the west side of the street. It has a west face, which is from ten to twenty-five feet in height. The stone is very similar to that at other quarries producing crushed stone in this area.

The major joints strike N. 50° E. The quarry is equipped with a crushing plant and the production is exclusively broken stone.

THE ELMER QUARRY.

The two principal openings comprising this quarry are located near the junction of 44th and Kansas streets. They were not being worked in 1902, but were formerly operated by Matt and Henry Elmer, under the firm name of Elmer Bros. The "building stone" ledge is worked here as

at the Tanner quarry. The stone has a yellowish buff color and is very shelly.

THE FEEBECK QUARRY.

This quarry is located on 44th street between Tracy and Virginia streets. It is owned by Sutherland Bros. and is operated by John Feebeck. It has a south face about 50 feet long. The marketable stone is obtained mainly from the "building stone" ledge. The stone splits along wavy bedding planes into beds from two to eight inches thick. The quarry is covered with from six to ten feet of loess. It is worked intermittently, when there is a demand for the stone. Two or three men are usually employed.

THE GRADY QUARRY.

This quarry is located at the corner of 42nd street and Highland avenue. It is operated by T. F. Grady and has been worked during the past four years. It is situated on the west side of the hill and has a face 250 feet long. The stripping consists of from twelve to twenty feet of loess and clay. The stone is obtained chiefly from the building stone ledge, which, at this place, consists of a lower bed of two feet eight inches of blue, argillaceous, fossiliferous limestone, having stratification planes, along which it can be split. Above this is seven feet six inches of gray, finely crystalline, fossiliferous limestone, consisting of beds from two to twelve inches in thickness, separated by wavy bedding planes. Along the bedding planes the stone has a buff color. The uppermost two feet is very good stone, but underneath this there is a very shelly ledge of two feet. The major joints strike N. 35° to 40° E. and N. 45° W. They are open and filled with clay.

The stone is pried up with crowbars and broken into irregular rubble with sledges. Five men are employed during the season.

THE HILL QUARRY.

Mr. J. B. Hill operates a quarry at the foot of the bluff at 1st and Lydia streets. It has been opened along the north side of the bluff for 250 feet and the stone is obtained from the lowest ledge which outcrops at this point. The following is a section of the quarry from top to bottom:

4-6 ft.		Clay and gravel stripping. Glacial boulders of granite are found in this stripping.
1 ft.	8 in.	Very fine grained, compact, black limestone; bed will cap easily eight inches from the top. Spalls easily and has a sharp fracture. This stone works well.
3 ft.	8 in.	Irregular beds of blue limestone, interstratified with shale beds from four to six inches thick.
4 ft.	6 in.	Solid bed of fine grained, bluish gray, fossiliferous limestone. The bed shows drusy cavities of calcite. It breaks into irregular rubble, but does not cap easily.

3 ft.	Compact, fine grained, gray limestone. Short, tight seams occur in this bed. The stone is colored in places with iron oxide and contains small seams and geodes of calcite.

The best stone is in the bottom bed. It works easily and has a uniform color. The four foot six inch bed is very difficult to cap and breaks into sizes suitable for building purposes. The uppermost bed has a very dark, uniform color and is very durable. It is not thick enough to produce large quantities of stone.

THE INMAN QUARRY.

This quarry is located at the corner of 26th street and Broadway. It is owned by Mrs. Dewey of 420 West 16th street, and is operated by Mr. P. Inman of 29th and Holly streets. When visited, this quarry had been opened about 150 feet east and west and about the same distance north.

The stone is covered with from six to fourteen feet of loess. The "building stone" ledge is being quarried, only the upper portion being used at present. The beds separate along irregular wavy bedding planes. It is expected to quarry the lower blue bed for building stone. This bed is twenty-six inches thick and can be easily capped.

The stone is a finely crystalline, gray limestone, containing small geodes of calcite. Short, tight seams occur throughout the ledge. The joints are from six to eighteen feet apart and strike N. 45° E. and N. 40° W. They are frequently open and filled with clay.

Twenty-five men are employed. One derrick is used in handling the larger blocks of stone.

THE JOHNSON QUARRY.

Henry Johnson owns and operates a quarry located at the north end of Elmwood avenue, on what are known as the North bluffs. It has a north face about 200 feet long. The following is a section of this quarry from top to bottom:

3-12 ft.	Loess stripping.
9 ft.	Building ledge. The upper seven feet consists of thin beds; the lower portion of two feet is blue, argillaceous limestone.
4 ft. 6 in.	Blue and drab shale, thinly laminated. Upper six inches very dark and carbonaceous.
1 ft. 4 in.	Shelly limestone.
1 ft. 6 in.	Shale.
11 ft.	Porous, gray, coarse grained, very fossiliferous, oölitic limestone. The stone is rather soft and weathers to a buff color along the joints. Small specks of iron oxide occur throughout the bed. Slight cross-bedding was observed.
1 ft. 6 in.	Laminated shale.
6 ft. 7 in.	Gray, fine grained, semi-crystalline limestone. Contains small geodes, nodules and small irregular veins of calcite. The ledge weathers to a buff color along the joints.

The eleven-foot ledge is known as the oölitic ledge. It is rather soft, but has proven to be one of the most durable building stones quarried in Kansas City. In retaining walls and foundations this stone has proved very durable. It works well, capping easily, into regular rubble. It is the most important ledge in the quarry. Posts, caps, sills, etc., made from this stone show reddish brown blotches, which are caused by iron oxide. The lowest ledge, known as the "Bull ledge," is difficult to work.

The quarry has been worked into the hill about fifty feet. A hand derrick is used in loading the stone.

THE KING QUARRY.

James King operates a small quarry at 25th and White streets, south of Sheffield. It is on the east side of the hill and has a face one hundred and twenty-five feet long and seven feet high.

It consists of rather heavy beds, the upper of which are the best. The stone in this bed is a fine grained, gray limestone fourteen inches in thickness. A layer of white flint nodules runs through the middle of the quarry. The stripping is light. The "building stone" ledge, near the crest of the hill, is worked intermittently.

The stone is being used for foundations. One or two men are employed.

THE KIRN QUARRY.

A small quarry operated by Mr. G. Kirn is located on Bellview street between 30th and 31st streets. It is situated on the west side of the bluff. The marketable stone in this quarry comes from the "building stone" ledge. It varies from a gray to a yellowish buff and is finely crystalline. Very little stone was taken from this quarry in 1903.

THE KNAPP QUARRY.

E. J. Knapp of Sheffield leases and operates a quarry one and one-half miles south of Sheffield. The quarry has a south face 315 feet long.

The stone is obtained chiefly from the "building stone" ledge. The stone in the upper one and one-half feet is decomposed. The remainder, with the exception of the bottom blue bed, is colored yellow with iron oxide and can only be used for rough masonry. The quarry is covered with not to exceed four feet of stripping.

The major joints strike N. 45° E. and are from six to ten feet apart. A minor set strikes N. 70° to 80° W. The quarry was not in operation when examined.

THE LANE QUARRY.

A small quarry, owned and operated by Mr. M. Lane of E. 29th and Jumbo streets, is located on Roanoke near 33rd street. It has an east

face 110 feet long. The stone is covered with from ten to twelve feet of clay. The entire building stone ledge is being worked into rubble. The beds have a dip of 2° into the hill.

The joints are from ten to twenty feet apart and strike N. 30° E. and N. 55° W. Two men are employed. One derrick is used.

THE M. V. LYLE QUARRIES.

Two quarries, operated by Mr. M. V. Lyle, are located, respectively, on Grand avenue between 25th and 26th and at the junction of 25th and Oak streets. The office of the company is at the quarry on Grand avenue. This quarry is on the west side of Grand avenue and has a face six hundred feet long extending nearly the entire distance between 25th and 26th streets. It is twenty-five feet high and consists of stone which caps the hills at this point. The stone is a fine grained, fossiliferous, gray limestone, containing small geodes, nodules and thin veins of calcite, which frequently have the outline of fossils. The beds contain many dries, which are stained with iron oxide. The stone splits along thin shale seams into beds from six to sixteen inches thick. It is weathered to a buff color from one to two inches on either side of the bedding planes. This margin is soft and shelly. The bedding planes are irregular and wavy. The heaviest ledges are near the bottom.

Clay seams striking N. 45° to 55° E. are prominent, and assist materially in quarrying. When visited, this plant was being operated about half the time.

The equipment consists of a crushing plant and the output is exclusively crushed stone.

The quarry at 25th and Oak streets has a face about 275 feet long on the north side of the bluff. The same ledge is worked as at the Grand avenue quarry. It has been in operation five years and considerable stone has been taken out. With the exception of the lower four feet, the entire ledge is used for crushed stone. The quarry is equipped with two crushers, a No. 3 and No. 4 Gates.

The quarries have a capacity of about 350 cubic yards of crushed stone per day. It is all consumed in the city for macadam and cement concrete work. An average of sixty men and from twenty-five to forty teams are worked at the two quarries.

The lower four feet of the ledge, which has not been quarried for crushing purposes, is now being worked by Mr. G. J. Lyle, son of M. V. Lyle, the entire product being rubble stone. This portion of the ledge separates into six or seven layers. The stone is a fine grained, bluish, argillaceous limestone, which works into a very good grade of rubble. Eight to ten men and four to six teams are worked in the quarry.

THE LYLE ROCK CO.'S QUARRY.

The quarry of the Lyle Rock Co. is located on 2nd street just north of Lexington. It is owned and operated by Charles H. Lyle and Fred M. Hayes. The office of the company is in rooms 204-205, Massachusetts building.

This company owns eight and on-third acres of land, lying between Lexington street and the Chicago and Alton railroad tracks. The quarry has an irregular south face about 300 feet long. The following is a section from the top to the bottom:

10-15 ft.	Loess. Stripping.
7 ft.	"Calico ledge." Erosion has removed this ledge at the west end of the quarry.
8 ft.	Shale.
9 ft.	"Building stone" ledge. Consists of two feet six inches of typical blue limestone at the bottom, overlain by seven feet of shelly rock.
4 ft.	Laminated, bluish black shale.
4 ft.	Compact, calcareous, yellow shale.
12 ft.	Soft, porous, fossiliferous, oölitic, gray to brown limestone. Contains small geodes and occasional small seams of calcite. The stone contains short tight seams along which it is stained yellow with iron oxide. Slight cross-bedding is common. The bed shows a number of thin shale seams along which the stone separates very easily.
1 in.	Blue shale. This layer increases in thickness in the bluffs to the east, being one and one-half feet thick at the Johnson quarry.
5 ft.	Fine grained, compact, gray limestone. Contains small geodes and thin irregular veins of calcite. Fossils are abundant. On either side of the joints the stone has been weathered to a buff color, to a depth of from one to two feet. This ledge is difficult to work advantageously.

Shale occurs beneath this level, outcropping at the foot of the bluff. To the north occurs the next lower bed of the general section. The upper portion of this bed contains many black chert nodules.

The oölitic limestone is the most valuable stone in the quarry, and at present it is about the only stone being quarried. It makes very good rubble and can be used for caps, sills and coursing. It is easily worked and can be split with a heavy sledge, very few plugs and feathers being needed. The ledge underneath the oölitic limestone is more difficult to work. The shale in this quarry is used by the neighboring brick yards. The quarry is being worked to the north and will soon pass through the bluff, after which it will be worked to the east.

The company employs about ten men and from eight to ten teams. The output is about 100 perch of stone per day.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.681
Porosity	9.148 per cent.
Ratio of Absorption	3.756
Weight per cubic foot	151.3 lbs.
Tensile Strength	941. lbs. per sq. in.
Crushing Strength	13,124. lbs. per sq. in. on bed.
	10,449. lbs. per sq. in. on edge.
Crushing Strength of samples subjected to freezing test	0644.7 lbs. per sq. in.

These tests show the stone to have lost on an average of 3,479.3 pounds per square inch, as a result of freezing and thawing. This is an appreciable amount and indicates that the stone is weakened by this weathering process.

THE W. C. LYLE & CO. QUARRY.

This quarry, which is owned and operated by F. M. Hayes and W. C. Lyle, is located at 41st and Olive streets. It was opened in 1902 on a tract of twenty-three and one-half acres of land owned by Mr. Hayes. The opening has a face fifty feet long, but it is intended to enlarge this by working along the outcrop.

The stone is quarried chiefly from the "building stone" ledge. The uppermost ledge in this quarry is twelve inches thick and separates into six-inch beds. Underneath this, the stone occurs in thin beds which are weathered along the bedding planes. The blue bed at the base of the quarry had not been developed to any extent at the time the property was inspected. The office of this company is located in Rooms 204-205 Massachusetts building.

THE LYONS QUARRY.

This quarry, which is owned by Mrs. Squires and operated by James Lyons, is located at 45th and Charlotte streets. It has been opened along the north side of the hill for 240 feet and has been worked into the hill forty feet. The stone is covered with from three to five feet of clay and loess, immediately underneath which lies the "building stone" ledge. The uppermost seven feet of this ledge consists of thin beds of finely crystalline, gray limestone, containing thin veins of calcite. The beds, which are from two to eight inches in thickness, are separated from one another by irregular wavy parting planes. Along the joints and bedding planes, the stone has been weathered to a yellowish buff color. The bottom ledge, which is two feet six inches thick, consists of a fine grained, argillaceous, blue limestone which splits readily along shaly bedding planes into pieces sufficiently thick for curbing. The upper portion produces rubble and building stone.

The major joints strike N. 45° E. and N. 45° W. The first set is the more prominent. They occur from six to fifteen feet apart and are of material assistance in quarrying.

Four or five men are employed at this quarry. A hand derrick is used for moving the heavier blocks.

THE McGILL QUARRY.

This quarry, which is operated by Mr. Samuel McGill, is located on the west side of the bluff at 29th and Genessee streets. The same stone is quarried as at the Kirn quarry previously described.

THE McTERNIN & HALPIN QUARRIES.

This firm operates two quarries, one of which is located on Highland avenue between 28th and 29th streets, and the other between 27th and 28th streets and Euclid and Garfield avenues. Both quarries are working the same beds. The face of the quarry on Highland avenue extends the entire length of the block, and is thirty feet in height at the middle. At the south end of the quarry, the lower five feet is being worked for building stone. This stone is a fine grained, compact, argillaceous, blue limestone, which has weathered to a buff color along the jointing planes. It is somewhat similar in appearance to the lowest bed of the "building stone" ledge. It works well into sills, caps and rubble. The upper part of the ledge is a fine grained, fossiliferous, gray limestone, containing nodules, crystals and fine irregular veins of calcite. This part of the ledge separates along wavy bedding planes into beds from six to sixteen inches in thickness. Some of the heavier beds, which occur near the base of the quarry, could be used for heavy footing. At present, all of the stone is being crushed.

This quarry is equipped with a crushing plant, having a No. 6 Gates crusher, bucket elevator and screen. Steam drills are used. The product consists of what is known locally as one and one-half inch macadam, binder, toothing and dust. The binder is crushed stone which has a diameter of from one-half to three-fourths of an inch. Toothing is crushed stone about the size of a kernel of corn. Dust is the finest product which comes from the crusher. Eighty-five men are employed.

The quarry between Euclid and Garfield avenues has a west face about 450 feet long and has been worked into the hill about 200 feet. It has been condemned for park purposes and will be abandoned within a year. The same rock is quarried as at Highland avenue. The stone from the lower five feet is used for rubble, while that from the upper twenty-five feet is used almost exclusively for crushing. The stripping consists of from six to seven feet of clay, which increases in thickness as the quarry is worked to the east.

This quarry is equipped with No. 1 and No. 4 Gates crushers, having a combined capacity of 200 yards per day. About fifty men are employed.

THE OWENS QUARRY.

This quarry, which is owned by Robert Owens, and leased by Mr. J. A. Cogan of Weir City, Kansas, is located at 27th and Tapping streets. The quarry has a face 500 feet long and has been worked into the hill about 100 feet. The "building stone" ledge which is quarried at this place has the same general characteristics as at the quarries previously described.

THE REARDON QUARRY.

The Reardon quarry, which is owned and operated by Michael Reardon, is located at 49th and Main streets. This quarry has a north and east face which together are about 625 feet long. The stripping consists of an average of seventeen and one-half feet of loess. The building stone ledge which is worked at this quarry has a vertical face of nine feet. The lower two feet six inches is the typical blue bed, while that above is typical of the upper portion of the "building stone" ledge. The stone in the lower bed is broken with plugs and feathers into heavy rubble, while that above is broken into smaller dimensions. The bedding planes are irregular and wavy. The rock shows dries, along which the stone is stained yellowish red with iron oxide.

Formerly this quarry was operated quite extensively for curbing, but the principal output at present is heavy rubble, obtained from the lower portion of the quarry.

Mr. Reardon owns several small openings west of this quarry which have not been operated for some time.

SAMUEL AND HOLMES CONSTRUCTION CO'S. QUARRY.

The quarry operated by this company is located one block north of Turner Bros. quarry, on the west side of Roanoke boulevard. A thirty-foot face of limestone is being quarried. It is all crushed at the quarry into sizes suitable for macadam, concrete and ballast.

THE SHEFFIELD QUARRIES.

A number of small quarries are opreated in the vicinity of Sheffield near the eastern limits of the city. These are all in the Bethany Falls limestone, which outcrops along the west bluffs of the Blue river. The ledge, on which the quarries are located, consists of about eighteen feet of fine grained, gray limestone, the upper two or three feet of which is badly decomposed. The bed immediately underneath this has a mottled gray color. The principal bedding plane occurs six feet four inches from the top of the ledge. The lower portion of the quarry splits into rather heavy beds of finely crystalline, compact, gray limestone, which

works better than the mottled limestone above. Short tight seams are common in the lower beds. In places, the stone is stained yellow with iron oxide. Owing to the steepness of the hill, the stripping increases rapidly.

The following persons operate quarries along these bluffs:

Mr. E. W. Knapp, residence 825 Ewing avenue, quarry corner 9th and Cambridge streets; Mr. C. W. Chenoworth, quarry northwest corner 8th and Cambridge streets; Mr. Wm. Oldram, quarry southwest corner 8th and Cambridge streets; Mr. Frank Masten, quarry directly south of the Knapp quarry; and Mr. Warren Jewell, quarry Cambridge between 9th and 10th streets.

These quarries are all being worked for rubble and operate a quarry face from 50 to 100 feet in length. From two to five men are employed. Only hand tools are used in quarrying.

LABORATORY TESTS.

Physical Tests.—Two-inch cubes of Bethany Falls limestone from the Knapp quarry showed a specific gravity of 2.672; a porosity of 3.150 per cent.; a ratio of absorption 1.189; and a weight per cubic foot of 163.6 pounds.

The tensile strength of this stone was determined to be 713.25 pounds per square inch; the transverse strength was 1,644.5 pounds per square inch; and the crushing strength was 13,140.6 pounds per square inch on bed and averaged 12,710 pounds per square inch on edge. The crushing strength tests show that there is little difference in the compressive strength of this stone on edge and on bed.

Samples were subjected to the freezing test and when broken were found to have a crushing strength of 14,250.7 pounds per square inch, which is higher than that of the fresh samples. These tests indicate that there is very little difference between the fresh and the frozen samples, the strength of the latter, in this case, being higher than that of the former.

THE SNELL QUARRY.

This quarry, which is owned by Mr. Gates and operated by John Snell, is located at 27th street between Highland and Woodland avenues. It has a nine-foot vertical face which separates into the following beds:

18-20 in.	Fine grained, compact, blue limestone, containing nodules of calcite.
3 ft. 6 in.	Fine grained, compact, variegated light and dark colored limestone. Central portion contains occasional cavities filled with bitumen.
10 in.	Fine grained, gray limestone.
18 in.	Dark, bluish colored limestone. Hard and brittle breaking with a sharp fracture.

Locally, this is known as the "Calico ledge." The stone is hard and

brittle and does not work as easily as the building stone ledge. The stone has every appearance of being a good limestone for macadam.

This quarry is worked with hand tools and only three or four men are employed.

THE SULLIVAN QUARRY.

This quarry, which is located at 43rd and Olive streets, is not now active. It is leased at present to Mr. Geo. Botham, who expects to operate it in the near future. The stone is obtained from the "building stone" ledge, which has a north and south face 75 feet long. The stone is very similar to that at the Tanner quarries, described on a following page. The stripping consists of from eight to ten feet of clay and soil. A hand derrick has been used in moving the heavier blocks of stone.

THE SUTHERLAND STONE CO.'S QUARRIES.

James and John Sutherland, who comprise this company, operate three quarries, two of which are located on Vine street between 26th and 27th, and the third of which is located at 24th and Woodland streets. This company has made a specialty of curbing which they have produced extensively during the last fifteen years. Owing to the decreased demand for limestone curbing, these quarries are not operated very extensively for this purpose, the output being mainly rubble. The curbing which is manufactured is used mainly for repairing that which is now in use.

The west quarry, on Vine street, has been opened practically the entire distance between 26th and 27th streets. The east quarry is near 27th street and has an east and west face of 200 feet and a north and south face of 250 feet. The strata in the west quarry dip slightly to the west, while those in the east quarry have a gentle dip to the east. The quarries have a stripping of loess of from twenty to twenty-five feet. The stone is obtained from the "building stone" ledge. The lower two feet six inches consists of argillaceous, blue limestone, which splits along rather irregular stratification planes into three eight-inch beds, which are used for curbing. The lower six inches of this bed is not used for this purpose because of its extremely argillaceous nature. Coursing, range and rubble stone have been produced from these beds. The stone breaks with a sub-conchoidal fracture and works well under the hammer.

The upper portion of the ledge consists of six and one-half to seven feet of fine grained, gray limestone. This stone is not as much decomposed as usual in this portion of the ledge. In some parts of the quarry, the beds have a thickness of twenty inches and split quite readily along thin shaly seams. Weathering has changed the color of the stone to a buff for about six inches on either side of the joints.

The major joints strike N. 45° E. and the minor joints N. 45° W. The joints in these systems are from six to twelve feet apart. The stone used for curbing is broken with plugs and feathers at right angles to the northeast-southwest joints. The blocks are cut and dressed to the required length and thickness.

The quarry at 24th and Woodland streets was not being operated at the time it was examined.

THE TANNER QUARRY.

This quarry, which is owned by William Tanner of 35th and Prospect streets and operated by P. Adams, is located on 42nd street between Olive street and Wabash avenue. It consists of two openings situated on the west side of the hill. The north opening has a face 150 feet long and the stone is obtained from the "building stone" ledge. The lower two feet six inches is a sub-crystalline, bluish colored, argillaceous limestone, weathered to a buff along the jointing and bedding planes. It has been used for caps, sills and curbing. The upper portion consists of thin, roughly bedded stone which is broken into rubble. Two feet from the top of the ledge is a very good eight-inch bed. The qaurry is covered with fourteen feet of stripping, consisting of eight feet of loess and six feet of bluish shale.

The joints are from six to twenty feet apart and strike N. 45° E. and N. 45° W.

The second opening is south of the first. The stone is obtained from the same ledge as in the first opening and is not essentially different in quality. This opening was not being worked when the quarry was examined.

The principal product of the quarry is rough rubble stone.

THE TURNER BROS. QUARRY.

This quarry, which is owned and operated by Turner Bros. of Kansas City, Kansas, is located at 36th and Roanoke boulevard. It has east and north faces having a combined length of 325 feet. The stone is obtained from the "building stone" ledge, the upper portion of which splits along irregular bedding planes into blocks which are more solid than ordinary. The lower two and one-half feet of blue limestone splits readily just below the middle of the bed. It is broken into large sized rubble and footing stone. It is weathered to a buff color along the jointing planes, which strike N. 40-45° E. and N. 30° W. The quarry is covered with twenty-one feet of reddish and yellowish shale.

The equipment consists of four hand derricks and hand tools. The product of the quarry is used chiefly by the company in contract work.

THE WALLS QUARRY.

The quarry operated by John M. Walls is located on Virginia avenue between 43rd and 44th streets. It has been opened about 100 feet along the east side of the hill. The stone is similar to that in the Feebeck quarry and is covered with nine feet of clay stripping. It was not in operation when visited.

THE WALTERS QUARRY.

This quarry, which is located east of 43rd and Oak streets, was not in operation when visited. It has a face 100 feet long and a stripping of four to five feet of loess. The stone is essentially the same as that obtained at the Lyons quarry previously described.

THE WASHINGTON CEMETERY CO'S. QUARRIES.

This company operates two quarries located on the cemetery grounds east of Sheffield. One of these is located east of 9th street and the other near the crest of the hill one-quarter of a mile east.

The quarry near the east end of 9th street has a face 225 feet long and twenty feet high. It is covered with six feet of clay stripping. The stone belongs to the Bethany Falls formation and is a fine grained, gray limestone, which breaks irregularly and is somewhat difficult to work.

This quarry is equipped with a permanent crushing plant, consisting of a No. 3 Gates crusher, a 25-horse power engine, a 30-horse power boiler and a bucket elevator. This plant is situated just south of the above described quarry. All of the stone is crushed.

The quarry near the crest of the hill is in the "building stone" ledge. The upper bed consists of from eight to twelve inches of finely crystalline, bluish gray limestone, having a buff color along the bedding planes. Underneath this are four inch, ten inch and four inch beds of finely crystalline, compact, gray limestone. This stone is not as badly decomposed as that in the Kansas City quarries. It is all broken into rubble which is now being used in retaining walls and stone fences about the cemetery property.

MAYSVILLE.

THE J. C. SPARLING QUARRY.

This quarry, which is owned by J. C. Sparling and operated by M. D. Sparling, is located in the N. E. ¼ of the S. E. ¼ of sec. 2, T. 58, R. 31 W., two miles southeast of the city. It has been operated three years and has a west face 250 feet long.

The following is a section of the quarry from top to bottom:

1-6 ft.		Soil and clay stripping.
1 ft.	2 in.	Fine grained, compact, buff colored limestone, containing calcite geodes.
	10 in.	Fine grained, buff colored limestone, splits into two beds. Weathers rapidly.
	6 in.	White shale.
	4 in.	Granular, soft, yellowish brown limestone, used for well rock.
	8 in.	Fine grained, fossiliferous, blue limestone, colored buff along bedding planes. Contains small calcite geodes.
	8 in.	
	12 in.	Finely crystalline, dark blue limestone. Contains calcite geodes.
	8 in.	Fine grained, blue limestone.

The major joints strike N. 10° W. and N. 50° E. They are well defined and are from fourteen to twenty feet apart in one direction and ten to twelve feet apart in the other.

The stone in the lower portion of the quarry is solid and works well into coursing and ashlery. The buff stone immediately above the blue beds is a soft granular rock which disintegrates rapidly when exposed to the atmosphere. This stone is also quite argillaceous. It is used principally for well rock. The stone from the upper beds will not stand frost unless thoroughly seasoned.

The necessity for removing the soil, clay and buff colored stone adds greatly to the expense of working the blue stone. Hand tools are used in quarrying.

MILAN.

THE VEATCH QUARRY.

The quarry owned and operated by A. N. Veatch is located in sec. 2, T. 62, R. 20 W., just west of the Omaha, Kansas City and Southern railway.

The following is a section of this quarry from top to bottom:

4 ft.		Clay stripping.
1 ft.	10 in.	Gray limestone. The upper bed of eight inches is light gray and very hard.
	4 in.	Blue shale.
3 ft.		Compact, fossiliferous, gray limestone. Consists of beds two to four inches in thickness, separated from each other by irregular bedding planes.
	9 in.	Blue shale.
3 ft.	3 in.	Crystalline, dark gray substance. Consists of nine or ten beds four inches in thickness.
1 ft.	2 in.	Finely crystalline, bluish gray limestone. The upper surface has a buff color as a result of weathering. Splits into two seven-inch beds.

The major joints, which are open and filled with clay, strike N. 55° W. and N. 30° E. They dip 20°, S. 35° W. and S. 60° E. The beds have an apparent dip of 5° S.

The main body of the limestone is fine grained and compact, although

the bedding planes are rough and irregular. The lower fourteen inches might be used to advantage for heavy footing stone. The thin shaly seams in the remainder of the quarry separates the stone into thin beds.

This stone was used in the foundation of a building which has been burned to the ground twice. The edges and corners of the blocks have flaked off, but, as a whole, the wall is still solid, sustaining perfectly the new superstructure.

MOORESVILLE.

THE CLARK QUARRY.

This quarry is about three-fourths of a mile southwest of Mooresville and about one-fourth of a mile west of Springtown. The quarry is owned by Mr. Walter W. Clark and operated by Mr. R. T. Smithers of Brookfield, Missouri. It is on the east side of a low hill, into which quarrying has extended for a distance of about 100 yards. The quarry face has an irregular oval shape and will measure altogether about 500 yards in length. The best stone for constructional purposes occurs along the west face. The thickness of the face at this place is about twenty feet and is made up of the following beds from the top to the bottom:

2 ft.		Broken limestone, covered with black soil.
3 ft.		Very much decomposed yellowish shale.
1 ft.		Dark, carbonaceous shale.
4 ft.	6 in.	Yellowish blue shale.
3 ft.		Very dark gray limestone. Used for rip rap.
3 ft.	6 in.	Dark gray limestone, showing suture joints. This bed can be split into two layers one and one-half and two feet in thickness. The two foot layer shows a less distinct bedding plane along which, in places, it may be capped. This stone contains occasional calcite geodes. It has been quarried for building purposes.

The north face consists of eight or nine beds of white limestone varying from six to eight inches in thickness. These beds are used for steps, sills, flagging, etc. The quarry is equipped with a hand derrick, most of the work being done without modern machinery.

It has been worked intermittently for thirty or forty years. During the last fifteen or twenty years an average of from five to thirty men have been employed during the quarrying season. Until recently the Burlington railroad had a spur to the quarry for the purpose of hauling out rip rap and ballast.

NODAWAY.

THE BURLINGTON RAILROAD CO'S. QUARRY.

This quarry, which is located one mile south of the depot, at Nodaway, is owned and operated by the Burlington railroad. Mr. J. C. Young, of Nodaway, is superintendent of the quarry. It was opened in

1901, and at the time inspected the work had consisted mainly of breaking up the boulders which make up the talus slope. The face of the cliff, which it is intended to quarry, has a depth of twenty-two feet and consists of gray limestone. A very prominent bedding plane divides the beds roughly into two eleven foot ledges. The entire face of the quarry is broken by bedding planes into layers from six inches to one foot in thickness.

The stone is very much alike in all the beds, being a finely crystalline, argillaceous limestone. The stripping has a maximum thickness of nine feet at the edge of the quarry, but will increase considerably as the work is extended into the hill. The major joints strike N. 40° E. and N. 60° W. and are from ten to fifteen feet apart. The quarry faces the south and has a length of 1,000 feet. The floor is twenty-five feet above the railroad track.

The stone which is being worked at present is unfit for anything except rip rap, ballast, macadam and foundation work.

PARKVILLE.

THE DANIEL BROS. QUARRY.

This quarry, which is owned and operated by John and James Daniel, is located east of the Burlington railroad one mile above Parkville. It is situated at the top of one of the river bluffs and was opened in the spring of 1903. Up to this time, the company worked a quarry at the base of the bluff just north of the new quarry.

The new one has a west face 200 feet long and twenty-two feet high. It has been worked into the hill about forty feet. The lowest bed is from twenty to twenty-four inches thick, and consists of finely crystalline, compact, dark gray limestone, containing thin veins of calcite. The bed is overlain with six inches of shale. Above the shale are six feet of badly decomposed shelly limestone. Above this is a twelve and one-half foot horizon of finely crystalline, bluish gray limestone occurring in beds from three to eight inches in thickness, separated from each other by thin layers of shale. When blasted, these beds break into pieces which require very little sledging before being fed into the crusher. Above these beds occurs a fourteen-inch layer of finely crystalline, blue limestone, which breaks into large rectangular blocks along jointing planes. This stone is suitable for coursing and well adapted for footing or heavy bridge abutments. It is the best stone observed in this vicinity. The quarry is covered with ten feet of soil and shale stripping. The major joints strike N. 35° E. and N. 30° W. and the beds dip slightly into the hill.

This quarry is equipped with a No. 4 Gates crusher, a 25-horse power

engine, a 30-horse power boiler, a bucket elevator and a screen. At present all of the stone from the quarry is broken in the crusher. It is separated into different sizes and carried by means of a long chute directly into the cars. Thirty men are employed at the plant and quarry. The output is used mainly for railroad ballast and concrete.

PLATTSBURG.

Two quarries, known as the Attebury and the Trimble, are located near Plattsburg. These are only operated when there is a local demand for stone. All the hills in this vicinity have outcroppings of similar stone, and a number of other openings have been made by different parties for the purpose of filling special contracts. The strata belong to the Upper Coal Measures and consist mainly of limestone and shale.

THE ATTEBURY QUARRIES.

Two quarries, owned and operated by James J. Attebury, are located about three-fourths of a mile east of Plattsburg. One of these quarries has been operated about eight years, but was not being worked when inspected in 1901. The following is a section of this quarry from top to bottom:

1-2 ft.	Soil stripping.
3 ft.	Compact, fossiliferous, gray limestone. Splits into beds two to four inches in thickness, along very irregular bedding planes. Very poor stone.
2 ft. 4 in.	Compact, gray, fossiliferous limestone, splits into beds from four to six inches in thickness.
10 in.	Fossiliferous, gray limestone. This bed contains dries.

Most of the beds in this quarry are very thin. Good rubble can only be obtained from the bottom bed.

The second quarry, from which most of the stone is now taken, is situated near the crest of the hill, east of the house. It has a stripping of from two to five feet of broken stone and red clay, and four feet of blue shale. Underneath this are two ten-inch beds of compact, fossiliferous, dark gray limestone, which together constitute the working face of the quarry. The stone in the upper bed has been weathered to a buff color along the jointing and bedding planes. The central portion of the bed is unaltered and has a bluish gray color.

The major joints strike N. 52° E. and N. 37° W.

THE TRIMBLE QUARRY.

The quarry owned and operated by J. A. Trimble is located about one mile north of Plattsburg, in the N. E. ¼ of the S. W. ¼ of sec. 13, T. 55, R. 32 W. The face extends about 225 feet along the top of a hill,

and consists of a one foot seven inch bed of very fossiliferous, gray limestone. It contains spots of iron oxide that impart a buff color to a portion of the stone. In some parts of the ledge, the fossils occur in layers, giving the stone a banded appearance. This ledge is overlain with from two to four feet of blue shale and three feet of broken limestone. The major joints strike N. 20° W. and N. 75° E.

The quarry is only operated when there is a local demand for footing or heavy foundation stone. It has been used in the public school buildings and for sidewalks, crosswalks and curbing.

THE HAWKINS QUARRY.

A small quarry was operated for about two years by W. H. Hawkins, near the western limits of the town, in the N. W. ¼ of the S. W. ¼, sec. 23, T. 55, R. 32 W. It has since been abandoned on account of the undesirable character of the stone.

PRINCETON.

Two quarries have been opened in the Bethany Falls limestone on the hills about two and one-half miles south of Princeton. At this place the beds are comparatively massive and the stone has been used quite extensively for bridge abutments and other heavy constructional work. The quarries are owned by Dr. F. R. Fullerton and Mr. T. W. Ballew, both of Princeton.

THE FULLERTON QUARRY.

This quarry is located about two and one-half miles south of Princeton, in sec. 9, T. 64, R. 24 W. It has a face 300 feet long, consisting of heavily bedded Bethany Falls limestone. The following is a section from top to bottom:

10 ft.	Clay stripping.
4 ft.	Gray limestone, containing numerous spots of red iron oxide. This bed is quite porous.
4 ft.	Gray limestone. The brown iron oxide occurs in bands throughout the bed.
2 ft.	Medium grained, crystalline dark gray limestone, stained with iron oxide.
1 ft. 8 in.	Finely crystalline, light gray limestone, containing very little iron, but occasional geodes of calcite and small fossils.

The major joints strike N. 22° E., N. 55° E. and N. 40-45° W. These joints are from ten to thirty feet apart and frequently contain from six to twelve inches of red clay.

With the exception of the lower layer, the stone is very little affected by frost and can be quarried at any season of the year. The lowest ledge, which is the hardest and most compact in the quarry, must be seasoned

before being used. The porosity of the stone decreases from the top to the bottom of the quarry.

The red iron oxide increases in abundance from the bottom to the top of the quarry. It occurs as a fine powder filling small cavities. When exposed at the surface it washes away, leaving the stone with a pitted surface. In parts of the quarry, the two lower beds are solid, while at other places they are separate and distinct. In some parts, the entire face consists of two beds, while in other places the upper bed exhibits parting planes from fourteen to sixteen inches apart.

The stone is quarried in large rectangular blocks which are handled with derricks. The four-foot beds are split into two foot layers as required by the Chicago, Rock Island and Pacific railroad, to which the entire output of the quarry was sold in 1902.

The quarry is equipped with a derrick and steam drills. It is 800 feet from the railroad, to which the stone is hauled by team. It is expected that, very soon, a side track will be laid from the quarry to the railroad. When this is done, the quarry, which is fifty feet above the valley, will be connected with the side track by a tramway. Twenty-five men are employed during the summer months.

Although the stone is now being used exclusively for bridge abutments, it is also suitable for foundations, crosswalks, retaining walls and crushed products.

LABORATORY EXAMINATION.

Chemical Analysis.—The following is a chemical analysis of a sample of stone from the lower ledge of this quarry:

Insoluble	1.88
Fe_2O_3, Al_2O_3	.78
$CaCO_3$	96.22
$MgCO_3$	1.01
Total	99.89

The above chemical analysis shows this to be very pure limestone, containing less than 4 per cent. of the usual accessory constituents.

Physical Tests.—Two-inch cubes of limestone from this quarry were tested in the laboratory with the following results:

Specific Gravity	2.585 upper bed. 2.689 lower bed.
Porosity	10.04 per cent upper bed. 4.92 per cent lower bed.
Ratio of Absorption	4.304 upper bed. 1.923 lower bed.
Weight per cubic foot	145.4 lbs. upper bed. 160.7 lbs. lower bed.
Tensile Strength (stone from lower ledge)	1025 lbs. per sq. in.
Tensile Strength (stone from upper ledge)	730 lbs. per sq. in.

Transverse strength (stone from lower ledge)	2685.02 lbs. per sq. in.
(Stone from upper ledge)	1075.6 lbs. per sq. in.
Crushing Strength	5,714 lbs. per sq.in. on bed. Upper bed.
	5,774 lbs. per sq.in. on edge. Upper bed.
	11,696 lbs. per sq.in. on bed. Lower bed.
	12,152 lbs. per sq.in. on edge. Lower bed.
Crushing Strength of Samples subjected to freezing and thawing test	5,020 lbs. Upper bed.
	11,152 lbs. Lower bed.

THE BALLEW QUARRY.

This quarry, which is owned by T. W. Ballew and operated by Al. Phillips, is located about two miles south of Princeton on the Chicago, Rock Island and Pacific railroad in the N. ½ of the N. E. ¼ of sec. 4, T. 64, R. 24 W. This quarry was opened in 1892 and has a face extending along the hill over a quarter of a mile.

The stone is similar in most respects to that at the Fullerton quarry. The bedding planes are not continuous, the ledge splitting into rather thin beds at one point and becoming solid at others. The following is a section of this quarry from top to bottom:

10 ft.	Broken stone and soil. Stripping.
2 ft. 10 in.	Finely crystalline limestone, containing a very little brown iron oxide.
1 ft. 7 in.	Finely crystalline, dark gray limestone, containing iron oxide.
1 ft. 10 in.	Finely crystalline gray limestone.
1 ft. 4 in.	Finely crystalline, gray limestone.

The major joints strike N. 35° E., N. 45° E. and N. 40° W.

The quarry is equipped with a crusher, boiler, engine, etc. It is worked from March to December, during which time from ten to twelve men are employed. The stone has been used for foundations, sills, crosswalks, monument bases, concrete, macadam and bridge abutments. The Chicago, Rock Island and Pacific railroad has used this stone very extensively. It has also been used in Lineville, Allerton and Seymore, Iowa, and at Unionville, Missouri. One hundred car loads were shipped in 1900 and a similar amount in 1901; $1.00 a perch is obtained for rubble stone.

RICHMOND.

THE GARNER QUARRY.

This quarry, which is owned by Fletcher Graham and operated by E. B. Farrar, is located about three-fourths of mile north of the city, in the N. E. ¼ of sec. 25, T. 52, R. 22 W. This quarry was opened in 1878 and has been worked during the quarry season for the last ten years. It is situated on the crest of a hill and has an irregular face about 300 feet long.

The rock is a finely crystalline, gray limestone occurring in thin beds separated by very irregular wavy bedding planes. The upper bed,

eighteen inches thick, is a hard, brittle, dark gray limestone which is said to make a very good grade of quicklime. The stone is now used for well rock and foundations.

At the top of the hill, east of this quarry, is a twenty-inch bed of limestone which has been worked for footing stone. It can be split into two beds of ten inches each. It is fine grained and has a bluish color. On account of the size of the blocks, it is not quarried for ordinary foundation work. The major joints strike N. 34° E. and N. 60° W.

Four men are employed during most of the year.

SAVANNAH.

THE SCHUSTER QUARRY.

This quarry is located four miles north of Savannah, on the west side of the tracks of the Chicago and Great Western railroad. It is owned by Nelson Blakeslee and operated by Newton and Utter. B. A. Dickson is superintendent and manager of the plant.

The quarry was opened in 1897 and has been worked continuously ever since. It is situated on a hillside, along which it has been opened for about 1,200 feet. The following is a vertical section of the quarry from top to bottom:

12 ft.		Clay and shale stripping.
1 ft.	3 in.	Very dark blue, compact limestone. Does not stand freezing.
8 ft.		Dark blue, crystalline limestone. Splits into six or seven beds from six to twelve inches in thickness.
3 ft.	6 in.	Light gray limestone; splits into three layers. The upper is six inches the other two one and one-half ft. thick.
7 ft.		Light gray, medium grained limestone. Lower two ft. quite soft.
	1-3 in.	Blue shale.
4 ft.	6 in.	Solid bed of coarsely crystalline, fossiliferous limestone, containing nodules of flint. Occasional pieces of zinc blende occur in this bed.

A test hole sunk twenty-five feet beneath the floor of the quarry shows alternating beds of limestone and shale. The stone from this quarry does not stand freezing until seasoned. The eight foot and four foot six inch ledges are rather hard, compact stone. The seven-foot ledge is softer, especially the lower portion. The fifteen-inch bed at the top of the quarry is a finely crystalline, dense limestone of uniform color and texture. It is the best stone in the quarry for building. Heavy footing can easily be obtained from this bed. The stone is being used exclusively for concrete and railroad ballast. The stripping is done by contract at a cost of about twenty-two cents per cubic yard.

The major joints, which strike N. 60° W., are used very little in working the quarry. Dynamite is used in quarrying, since it is desired

PENNSYLVANIA LIMESTONE.

A section of the Farmer and Dunn quarry, St. Joseph, Mo.

to break the stone as fine as possible. The machinery consists of a steam drill, a Gates crusher No. 5, and a Brownwell stationary engine. The crushed stone is separated into two sizes, screenings and two inch. In 1901 the two-inch size sold at 60 cents and the screenings for 25 cents per cubic yard. The quarry is worked continuously except during the coldest weather. About forty men are employed and the value of the output in 1901 was $42,000.

ST. JOSEPH.

The Pennsylvanian or Upper Coal Measures in the vicinity of St. Joseph consist of alternating heavy beds of shale and limestone overlain with a variable but generally thick deposit of loess.

Limestone occurs at three different horizons. The upper two are the only ones quarried in this vicinity. The uppermost or surface ledge consists of from sixteen to eighteen feet of limestone which splits into beds from four to twenty-four inches in thickness. Underneath this occurs a heavy bed of clayey shale. Underneath the shale occurs a massive bed of finely crystalline limsetone, eighteen feet in thickness. Another bed of shale of about fifty feet underlies this limestone. This in turn is underlain with four feet of finely crystalline limestone. This bed is underlain by blue shale.

The middle limestone horizon is the most important and is the one from which most of the stone is quarried.

The principal output is crushed stone, although the upper portion of the middle ledge has been used to some extent for rubble.

The following are the quarries which are being operated in the vicinity of St. Joseph: Farmer & Dunn, Roth, Eagle Contracting Co. and Helsley Bros. With the exception of the last named, these quarries are all in the northern part of the city. The Helsley Bros. quarry is located about two and a half miles north of St. Joseph. The following is a brief description of each.

THE FARMER AND DUNN QUARRY.

A. M. Farmer and J. P. Dunn operate a quarry on the west side of the hill. The land on which it is located is owned by H. W. Dunn.

The quarry has a working face 250 feet long. The middle ledge of limestone has a thickness of seventeen feet, as developed in this quarry. The stone is covered with a heavy stripping of loess and clay which increases as the quarry is worked east.

The stone occurs in thick massive beds. The upper four to five feet is medium grained limestone, through which is disseminated particles of

iron oxide. Due to the iron, the stone has a gray to buff color. This bed is known as the "pudding ledge." It is used to some extent for rubble and works well under the cutting tools.

The remainder of the face consists of finely crystalline, heavily bedded limestone, having a gray to brown color. It is used almost exclusively for crushing.

The quarry is equipped with a Gates crusher No. 3, a 30-horse power boiler, a 25-horse power engine and other necessary accessories for quarrying.

H. W. Dunn formerly quarried another ledge near the crest of the hill, above the present quarry.

THE EAGLE CONTRACTING CO'S. QUARRY.

The Eagle Contracting Co. of Kansas City, Missouri, operated a crusher near the northeast limits of the city in 1902. The quarry from which the stone was obtained has a vertical face of about twelve feet. The stone has a gray to buff color, is fine grained and fossiliferous. When examined it was covered with from two to five feet of red clay stripping.

The company operates a No. 4 Gates crusher and is engaged exclusively in the production of crushed stone. Since visiting this quarry the company has located their crushing plant one mile north of the Roth quarry.

THE HELSLEY BROS. QUARRY.

The quarry owned and operated by Helsley Bros. is located in sec. 31, T. 58, R. 35 W., about two and one-half miles north of St. Joseph. It was opened in 1898 and has been operated almost continuously since that time.

The base of the quarry is about fifty feet above the tracks of the Burlington railroad, which skirt the west side of the bluff. Between the base of the quarry and railroad tracks there are about forty feet of blue shale, covered with ten feet of shaly sandstone. The quarry itself has a vertical face of fourteen feet, all of which is dark gray limestone. In places the stone contains considerable iron oxide, which occurs in spots and small veins. Portions of the quarry are entirely free from iron oxide staining, and at these places the stone has a very light color. This ledge is the same as that worked at the Farmer and Dunn quarry.

The quarry contains no prominent jointing or bedding planes.

Above the limestone bed, which constitutes the quarry face, there occurs a fifteen-foot bed of blue shale. At the south end of the present face of the quarry, a four-foot bed of very hard buff colored limestone occurs above the shale. On top of this is a stripping of loess clay.

This company owns thirty-nine acres of land extending for a distance of a half mile along the bluff. The quarry face is 300 feet long and can be extended at either end. The stripping costs about fourteen cents per cubic yard and although quite heavy, can be handled very cheaply. It is thrown into the quarry and dumped upon the hillside below by means of wheeled scrapers.

This quarry is equipped with modern machinery, including a Badger steam drill, Gates crusher No. 4 and a 75-horse power engine. The company produces four sizes of crushed rock for macadam, as well as stone for foundation work, sidewalks, paving, crosswalks, curbing, bridge abutments and concrete. On an average, forty men are employed at the quarry between April and December of each year. Most of the output is sold in St. Joseph and Marysville. Since this quarry was visited it has become the property of "The St. Joseph Street Construction Co."

THE ROTH QUARRY.

The quarry owned and operated by Frederick Roth is located just north of the Farmer and Dunn quarry. Two openings have been made, one near the crest of the hill and one lower down, in what is known as the second ledge. The latter is the one being operated at the present time.

The upper opening has a stripping of eighteen feet of loess, which is removed by washing the clay through a sluice-way to the valley below. The water is pumped from the valley for this purpose. In this opening there is exposed twenty-one feet of rock, which occurs in beds from two to twelve inches in thickness. The beds are separated by thin layers of shale. The stone is somewhat decomposed along the bedding planes. It is finely crystalline and contains fine veins of calcite and occasional flint nodules.

The stone is used mainly for macadam pavements. Some of the larger blocks have been used for foundations.

The lower opening has a face 725 feet long on the west side of the hill. This opening is now being operated at the south end and the stone is very similar to that obtained at the Farmer and Dunn quarry. It contains dries. The so-called "pudding ledge" is used to some extent for rubble. The remainder of the stone is crushed for macadam.

TRENTON.

Two quarries are being worked in the upper strata of the Lower Coal Measures near Trenton, Grundy county. The output is entirely rough rubble stone, used locally for foundation work. The quarries are operated by David Payne and M. P. Cole.

THE COLE QUARRY.

This quarry is located in the E. ½ of S. E. ¼, sec. 24, T. 61, R. 25 W., about two and one-half miles southwest of Trenton. It is owned by M. P. Cole and G. P. Bosley, and is operated by M. P. Cole. The quarry is situated near the top of a hill, along which it extends for about 1,500 feet. It has not been worked very far into the hill, the stone having been quarried where it was most accessible.

The uppermost four feet consists of four to six inch layers of finely crystalline limestone, containing many small cavities. The bedding planes separating these layers are sometimes tight, in which case the stone can be used for heavy foundation work. A fourteen-inch bed of finely crystalline, gray limestone underlies this heavy ledge. Underneath this is a thirty-five-inch ledge of fine grained, fossiliferous stone, having a light gray to bluish color. This bed can be split from the top to the bottom into 6 in., 4 in., 2 in., 4 in., 6 in., 5 in. and 8 in. beds. These are broken into light foundation stone, well rock and flagging.

The major joints, which strike N, 45° E. and N. 45° W., are sufficiently far apart to permit the quarrying of stone four feet in breadth by eight to twelve feet long.

This quarry was opened in 1883 and is worked to some extent each year. In the spring of 1902 the owners were opening a new quarry about one-fourth of a mile north of Mr. Cole's house.

THE PAYNE QUARRY.

The David Payne quarry is located two and one-half miles west of Trenton. It is situated on a hill side, along which it extends for about 150 feet. The quarry face is six feet deep and consists of the following beds from top to bottom:

2-4 ft.	Dirt stripping.
4 in. 4 in.	Light gray limestone. Beds are much broken. Used for well rock.
4 in. 6 in.	Light gray limestone, with occasional small vein-like streaks of iron oxide.
10 in.	Medium grained, light gray, fossiliferous limestone.
8 in.	Similar to bed above.
16 in.	Light gray, finely crystalline limestone. Best bed in the quarry.
6 in.	Light colored, crystalline limestone.

The joints strike east and west and north and south. Many of them contain iron oxide, which imparts a dark red color to the stone. These are known locally as "red seams." Thin laminae of shale occur along the wavy bedding planes.

The stone is quarried by prying it up with crowbars and breaking it into irregular pieces with sledges.

PART II. SANDSTONE.

BUTLER.

THE DAY QUARRY.

This quarry, owned and operated by J. T. Day, is located four miles south of Butler, in the S. W. ¼ of sec. 4, T. 39, R. 31 W. It has been worked intermittently since 1882. It consists of a single heavy bed of fine grained, micaceous sandstone, from 16 to 18 feet in thickness, which has been worked 160 feet along the north side of a hill. The quarry is being worked to the east, and the operating face extends 20 feet north and south at the east end of the opening. The stone in the upper six to eight feet is quite soft and is used only for foundations. It contains considerable brown oxide of iron, in the form of small specks, giving the stone a light buff color. The lower ten feet has a bluish gray color and contains occasional small nodules of iron sulphide which decomposes into iron oxide and eventually weathers out, leaving cavities. The lower three to five feet is practically free from iron sulphide. Parallel to the bed the stone contains thin leaf-like deposits of carbonaceous matter. When the stone is cut normal to the bed, these either do not show or appear simply as dark pencil marks. A piece of coal was observed imbedded in the sandstone near the top of the present working face.

The stone from this quarry is used almost exclusively for monument bases, although it is suitable for caps, sills and coursing. The massive character of the stone permits the quarrying of blocks of any desired dimensions. The quarrying and dressing are both done by hand. The rock is quite soft when first quarried, but hardens upon exposure.

The stratification planes dip to the southwest. In lifting the rock from the west to the east, as practiced at present, it breaks upward along the bedding. If the quarry were opened at the north and worked to the south or west, the stone would split downward instead of upward. This could be done easily, as the stone is exposed for a considerable distance along the side of the hill.

Hand channeling is practiced in getting out the blocks. The stone is channeled with long sharp picks to the required size and then lifted with plugs and feathers. This is the only quarry in the State where hand channeling is practiced.

CLINTON.

The town of Clinton is underlain by rocks of Lower Coal Measure age. The principal stone quarried at this place is a soft sandstone which outcrops near the edge of the town. The limestone layers are not thick enough to be of value for building stone. A number of quarries have been operated in the past at various points west and northwest of the city, but have been abandoned on account of excessive stripping. The quarries now in operation are the Harness, the Gilleau, the Swadner, the Craig and the Ehler. All of these quarries, with the exception of the Harness, are located near the northwest limits of the city.

An inspection of foundations and monument bases, built out of this stone, shows a considerable variability in its quality. That which contains shale seams is least durable. An inspection of steps shows that the stone is quite easily abraded.

THE EHLER QUARRY.

This quarry is located near the northwest limits of the city. It is owned by Mrs. L. M. Roberts and leased and operated by F. X. Ehler. It has been operated about twelve years and is worked intermittently during the summer. It has a west face 225 feet long and 12 feet high, consisting of a fine grained gray to buff colored micaceous sandstone. The stone, which is soft and friable when quarried, hardens when seasoned.

The following is a section of the quarry from top to bottom:

3 ft. 6 in.	Clay stripping.
3 ft.	Splits into three layers.
7 ft.	Solid in middle of quarry. Can be split into blocks of any desired thickness. In the natural outcrop it consists of layers from two to six inches in thickness.
9 in.	Solid bed.

This quarry is located on a twenty-acre tract of land, all of which is underlain by the same stone. A considerable quantity of fine sand, which has been washed into the quarry opening, is used locally for mixing mortar.

The beds have ripple marked surfaces and dip slightly to the southwest. The shale seams are not as prominent here as on the south side of the hill.

THE HARNESS QUARRY.

The Harness quarry, which is located one and one-half miles southwest of Clinton, just north of the Kansas City, Fort Scott and Memphis railroad, is owned by Joseph Harness. It has been idle for several

years. Quarrying has been mainly along the hillside where the stripping was light. Three separate openings have been made, from all of which the stone is very similar.

The stone is a fine grained, friable sandstone, having a gray to buff color, streaked and spotted in places with iron oxide. When first quarried it is quite soft and friable, but hardens considerably when seasoned.

The east opening, which faces the east, has been worked north and south 150 feet and east and west 50 feet. The stone occurs at this place in a three-foot bed which splits easily into layers of any desired thickness. This ledge is covered with from three to four feet of shelly stone and soil stripping. At the south end of the opening, the shelly stone is solid, forming a bed of about the same thickness as the lower.

The middle opening has been worked 150 feet north and south and 100 feet east and west. The workable stone consists of two beds aggregating from three to five feet in thickness. The stone in the lower is somewhat harder than that in the remainder of the quarry.

The west opening has a south face 100 feet long. It consists of a number of shelly layers, above which occur a three-foot bed of solid sandstone; two feet of sandstone in beds of varying thickness; and three feet of stripping. The stone in this opening is softer than in either of the others.

The joints are prominent, and strike north and south and east and west. They are from four to ten feet apart and greatly facilitate quarrying operations. No shaly seams were observed in this stone. It has been used for rip rap in the water reservoirs at Clinton and in the foundations of the Burrell Hotel, Washington Park Public School, and the White Swan elevator.

THE GILLEAU, SWADNER AND CRAIG QUARRIES.

South of the Ehler quarry, on the same hill, is a single opening which is worked as three quarries. The west quarry is operated by Peter Gilleau, the middle by John Swadner and the east by Mr. Craig. The Gilleau and Swadner quarries each have an east and west face of fifty feet, while the Craig quarry has an east and west face of 100 feet. Each of the quarries, with the exception of the Craig, from which the stone has been nearly exhausted, has 150 feet of ground north and south. The stone is a rather friable, fine grained, calcareous, micaceous sandstone. The color varies from a gray to a buff, weathering in time to a gray. The following section gives the succession of beds from top to bottom:

4 ft.	Clay and shale stripping.
3 ft. 6 in.	Shelly stone. Two six inch layers at top of the bed, used for flagging, curbing, well tops, etc.

1 ft. 3 in.	Bed having short, discontinuous shale seams parallel to base.
1 ft. 1 in.	Stone similar to bed above. Splits along a shaly seam three inches from base.
17 in. 8 in.	Similar to the beds above.
8 ft.	Lower 2 feet does not exhibit shale seams. Upper 8 inches very shaly.
4 ft.	Contains a number of shale seams.

The stone in these quarries contains an occasional nodule of iron sulphide. The upper ledges work best. The three-foot ledge breaks irregularly.

The shale seams make it imperative that stone from these quarries should be selected very carefully and never laid on edge. At the Gilleau quarry the lower four foot bed is not worked. At the Swadner quarry this bed, at present, is very poor stone, owing to its proximity to one of the major jointing planes.

The major joints strike N. 40° W. and N. 55° W. All of the stone from these quarries is used locally.

COLLINS.

There are two quarries in the vicinity of Collins, in both of which the stone is sandstone of Upper Carboniferous age. These quarries are known as the Martin and the White.

THE MARTIN QUARRY.

This quarry, which is located one and three-quarters miles south of Collins, is owned by Ed. Martin. For some time prior to the summer of 1902 it had not been active. The quarry has a south face 150 feet long. It has been worked to the north about 60 feet. Of the working face only five feet was exposed when the quarry was examined.

The stone is a medium grained, soft, friable sandstone, having a gray to dark red and sometimes variegated color. The exposed surface has a deep red color, resulting from the washing of iron oxide from the two feet of stripping. The upper one foot is cross bedded and very shelly.

The hotel across from the depot is built out of this stone and shows well its color and texture. Owing to inactivity the quarry was in very bad condition in 1902.

THE WHITE QUARRY.

This quarry, which is located four and one-half miles west of Collins, is owned by Jesse Rorich and operated by Chas. A. White. It has been opened about 80 feet east and west and has been worked 50 feet north and south. It has a maximum face of about seven feet. The beds

dip 8° a little west of south. The stripping consists of four feet of dirt and broken stone and two feet of cross bedded, shelly rock. There are from six to seven feet of workable stone, occurring in beds from two to six inches in thickness. These beds have ripple marked surfaces. The stone is a fine grained, micaceous sandstone, having a white to gray color, variegated in places with streaks and bands of yellow and red iron oxide. The stone breaks easily and with a straight fracture with plugs and feathers. It is used mainly for caps, sills, flagging and curbing. The ledges are mostly too thin for building stone. The two upper beds on the south side of the quarry are coalescing to form a single heavy ledge that will make good building stone. The sharp, fine grains of sand of which the stone is composed make it suitable for grindstones and whetstones, although its friability makes it wear rather fast. The flagging and curbing are gotten out in very good shape, and where traffic is light they wear for a long time.

KAHOKA.*

Three quarries are operated intermittently in the vicinity of this place to supply the local demand for building stone. These quarries are owned respectively by Mr. Wm. Casey, Mr. Story and Fulton & Creger.*

THE CASEY QUARRY.

This quarry is located about two and one-half miles north of Kahoka, in the S. E. ¼ of the N. W. ¼ of sec. 9, T. 65, R. 8 W. It was opened about 1859 and has been worked intermittently since that time.

The quarry has an east face of 150 feet and a north face of 60 feet. The north face, sixty feet high, consists chiefly of sandstone with several feet of limestone at the bottom. The following is a description of the beds in this part of the quarry from top to bottom:

6-10 ft.	Clay stripping.
5 ft.	Medium grained, white sandstone, in beds from ten to twelve inches in thickness. The stone in the upper bed is very hard.
2 ft. 6 in.	Light gray sandstone. Can be split into two layers.
3 ft. 3 in.	Light gray, sandy limestone. Can be split into layers six inches in thickness.
1 ft. 7 in.	Limestone containing dark colored chert nodules. This stone is difficult to work.

The sandstone is easy to quarry and breaks easily with a sledge or plugs and feathers. Good stone of almost any desired thickness can be obtained. Besides being used for foundations, it has been quarried for sills, caps, curbing and flagging. Monument bases of a light gray color can be obtained from this stone. The limestone bed at the base of the

*See under Limestone, part I of this chapter.

quarry is too thick for foundations and is difficult to split into sizes suitable for other purposes.

The major joints strike N. 44° E. and east and west. The stone is cross-bedded at the west end. The bedding planes are not persistent throughout the quarry.

LABORATORY EXAMINATION.

Physical Tests.—Two-inch cubes of stone from this quarry were examined in the laboratory with the following results:

Specific Gravity	2.622
Porosity	6.754 per cent.
Ratio of Absorption	2.762
Weight per cubic foot	154.7 lbs.
Crushing strength	11,260 lbs. per sq. in., on bed. 9,694 lbs. per sq. in., on edge.
Crushing Strength of samples subjected to freezing test	11,786.2 lbs. per sq. in.

From the above tests we see that the frozen samples had an average crushing strength of 526.2 pounds per square inch more than those that were fresh, which shows that the stone is very little injured by alternate freezing and thawing.

THE STORY QUARRY.

This quarry is located about three-fourths of a mile northeast of the Casey quarry. It consists of several beds of yellow sandstone, aggregating six feet in thickness. The face is about 50 feet long. The bedding planes are irregular and the beds dip northeast into the hill. The stone is covered with eight feet of clay, the removal of which is very expensive, considering the quantity of stone available.

LAMAR.

One quarry has been opened in the Lower Coal Measure sandstone near the southeast limits of the city, just north of the Kansas City, Ft. Scott and Memphis railroad. It is owned by B. A. Beamer of Lamar and has been operated intermittently since 1889. The quarry has a southeast face 900 feet long. The following is a description of the beds from top to bottom:

3 ft.		Dirt stripping.
1 ft.	6 in.	Shelly sandstone, highly colored.
1 ft.		Brownish buff, fine grained sandstone.
1 ft.	4 in.	Reddish to light colored, fine grained sandstone. This bed contains highly colored bands parallel to the bedding, especially in the upper portion.
2 ft.	4 in.	Brown to purple fine grained sandstone.

Two well developed sets of joints, striking N. 50° E. and N. 47° W., occur in this quarry. They are from three to ten feet apart and break

ASPHALTIC SANDSTONE.
Quarry and yard of the Liberal Stone and Coal Co., Liberal, Mo.

the stone into rectangular blocks. They are of great help in quarrying. The sandstone is somewhat micaceous and rather soft and porous. Stratification planes occur throughout the different beds and along these the stone splits very easily and with a very smooth fracture.

These beds lift easily along their bedding planes and blasting is not required in any part of the quarry. The stone breaks across the bedding with a very straight fracture, into rectangular blocks of any moderate size. The lowest bed furnishes large blocks, which are used for making watering troughs.

The color varies so greatly in the different beds that where the stone is laid on its bed, it would be impossible to construct a wall having a uniform color. In order to obtain a uniform color, the lower bed which has a quite constant purple color is split along the bed and laid on edge. Undoubtedly the stone is weaker when laid in this manner and if the superstructure is heavy it cannot be done without danger. Besides building stone, this quarry produces flagging and curbing which are used in Lamar.

LIBERAL.

The Lower Coal Measure sandstone, which outcrops in the vicinity of Liberal, is quarried both north and south of the city. The beds are thick and massive and break into very regular blocks. Stone can be obtained of any desired dimensions.

Three quarries are operated at this place, two of which are owned by "The Liberal Stone and Coal Co." and the third by W. H. Curless. The stone is essentially the same at the three quarries, excepting at the north quarry of the Liberal Stone and Coal Co., where it has been impregnated with bitumen or asphalt. The stone has been used mainly for buildings (local), bridge abutments, sidewalks and curbing.

THE LIBERAL STONE AND COAL CO'S. QUARRIES.

The asphaltic sandstone quarry, which is located two miles north of Liberal, in the N. W. ¼ of the S. W. ¼ of sec. 23, T. 33, R. 33 W., is owned by Mr. Geo. H. Walser and operated by Geo. H. Walser and C. H. Carter, Jr., under the firm name of "The Liberal Stone and Coal Co." This quarry is situated on the west side of a hill, west of the Missouri Pacific railroad, and has a west face about 300 feet long. It has been worked into the hill about 150 feet.

The stripping, which is thickest in the middle of the quarry, consists of from one to ten feet of shale and clay. In the stripping, about four feet from the bottom, occurs a six-inch bed of very hard, black, fossilifer-

ous, fine grained limsetone. Underneath this bed, the stripping is a yellowish clay, while above it is a carbonaceous shale and red clay.

The sandstone is very fine grained and micaceous, and has a black color, due to the asphalt content. It is somewhat harder than the stone in the other quarries of this place. It has faint stratification planes parallel to the bedding. These are short and discontinuous, never persisting throughout the length of the bed. They are very common in all parts of the stone.

The face of the quarry consists of one channel cut from three to four feet in depth. The beds dip slightly to the north and the channel cut increases in depth in that direction. The exact thickness of the workable stone is not known. That in the floor of the quarry is similar to that in the face.

The joints, which strike N. 20° E., are very prominent, and are from ten to fifteen feet apart. They are stained with iron oxide. Apparently there are no joints at right angles to this set.

The stone is sawed parallel to the bedding and cut into pieces suitable for crosswalks, sidewalks and curbing. The large amount of asphalt in this stone makes the absorption very low in comparison with that from the other quarries. On the sawed surface weathering sometimes loosens small pieces, which fall away leaving shallow depressions in the stone.

The company is obliged to haul the stone by team from the quarry to a nearby spur of the Missouri Pacific railroad. Derricks are used to load the cars.

Steam derricks, steam drills, channelers and gang-saws are used in getting out the stone. When in operation the quarry employs an average of ten men for nine months during the year. Owing to litigation, it is now idle.

This company owns another quarry one-half mile south of the city, in the W. ½ of the N. E. ¼ of sec. 11, T. 32, R. 33 W. The opening which is being worked consists of a cut 40 feet wide, 10 feet deep and extending into the hill about 200 feet.

The stone is a fine grained, slightly micaceous, grayish buff sandstone. Small spots of sulphide and flecks of oxide of iron are disseminated through it. The floor of the quarry is an arenaceous, micaceous shale, overlying a seam of coal which is mined in this region. Above the shale is a twelve-foot bed of sandstone, which, at the east end of the quarry, splits along a shaly seam, two feet from the floor. This parting plane does not continue through the quarry. The upper foot of the stone is badly decomposed. The beds have a dip to the east, and having a dip of 4° from the horizontal, are two very ferruginous streaks six to

eight inches wide. Owing to their position these streaks injure the otherwise uniform color of the stone.

The joints are from twenty to thirty feet apart, except in the western portion of the quarry, where they are considerably closer. They have a dip of from 9° to 11° W., from the vertical, and strike N. 36-42° W.

The quarry is connected by spur with the Missouri Pacific railroad. It is equipped with machinery, including a derrick, for loading the stone.

LABORATORY EXAMINATION.

Physical Tests.—Samples of both the ordinary and asphaltic sandstones from this quarry were tested to determine their strength and durability. The following are the results of the tests made on samples of the yellow sandstone:

Crushing strength	4,370.6 lbs. per sq. in.
Tensile Strength	202.6 lbs. per sq. in.
Transverse Strength	418.61 lbs. per sq. in.
Specific Gravity	2.70
Porosity	21.58 per cent.
Ratio of absorption.....	10.19 per cent.
Weight per cubic foot.....	132.3 lbs.

Crushing strength of samples subjected to the freezing test 8,188.7 pounds.

The following are the results of tests made on the asphaltic sandstone:

Crushing strength	9,002 lbs.per sq. in.
Tensile strength	344.5 lbs. per sq. in.
Tranverse strength	769.93 lbs. per sq. in.
Specific gravity	2.445
Porosity	7.01
Ratio of Absorption.....	3.05
Weight per cubic foot.....	142 lbs.

Crushing strength of samples subjected to freezinz test, 9.230 pounds.

An examination of these results indicates the superior quality of the asphaltic over the ordinary yellow sandstone. The asphaltic sandstone has a higher strength, crushing, tensile and transverse; the porosity is about one-third that of the yellow sandstone; and for the samples tested the asphaltic sandstone lost nothing in strength through freezing and thawing, while the yellow sandstone lost about 33⅓ per cent.

THE CURLESS QUARRY.

This quarry, which is located about a mile west of Liberal, in the N. W. ¼, S. E. ¼, sec. 2, T. 32, R. 33 W., is owned and operated by W. H. Curless of Liberal, Missouri. It consists of three openings situated near one another on the west side of a hill. The middle opening is the only one which is worked at present, although considerable stone has been quarried from the other two. The opening which is farthest north has been worked into the hill 150 feet and now has a face six feet deep and 200 feet long. The south opening has a twelve-foot vertical face, con-

sisting of several thick beds from which might be obtained stone of large dimensions. The stone contains an occasional cavity filled with iron oxide and near the bottom it is streaked brown with iron oxide.

The middle opening which is being worked contains the best stone in the quarry. The working face is about 250 feet long and consists of a single massive bed of sandstone eight feet in thickness. Above this bed occur a four-inch layer of shale, a six-inch bed of sandstone, eighteen inches of sandy shale, a twenty-inch bed of sandstone and four feet of alternating shale and sandstone in layers about four inches in thickness.

The stone is a fine grained, micaceous sandstone, varying in color from a gray to a buff, the latter color being due to small specks of disseminated iron oxide. Near the top of the quarry occurs a twelve-inch bed of reddish colored stone containing a higher percentage of iron oxide.

The major joints in this quarry, which are open from one to three inches, contain a heavy red plastic clay. These joints strike N. 55° W., N. 30° E. and east and west. The strike of a number of these is not constant in direction, varying from 15° to 30°.

The Knox system of blasting is used. The stone breaks with a very smooth fracture, splitting with plugs and feathers into blocks of almost any desired thickness.

A large part of the stone from this quarry has been used in bridge abutments, for which purpose it is well adapted. The prices obtained in 1901 for all work measured in the wall were as follows:

For dimensional stone	$3.00 per yard.
Ashlery, from 12-16 in. sq	2.50 per yard.
Bridge rubble stone 12-14 in. thick	2.00
Wall and culvert stone	1.75

LABORATORY EXAMINATION.

Microscopic.—An examination of the thin section of this stone under the microscope shows that it consists chiefly of roundish to sub-angular grains of quartz. The interstices contain calcite, kaolin, iron oxide and chlorite. The quartz individuals are small but quite uniform in size. The grains are not very firmly bonded together.

Physical Tests.—Two-inch cubes were subjected to strength and weathering tests with the following results:

Crushing strength	4942 lbs. per sq. in.
Tensile strength	306.5 lbs. per sq. in.
Transverse strength	708.9 lbs. per sq. in.
Specific Gravity	2.686
Porosity	22.95 per cent.
Ratio of absorption	10.23.
Weight per cubic foot	129.3 lbs.

Crushing strength of specimens subjected to the freezinz test, 5,742.7 lbs. per sq. in.

An examination of the above results indicates that the stone does not have a high tensile, crushing or transverse strength; that the porosity is high; and that the stone is apparently very little affected by alternate freezing and thawing.

MARSHALL.

The only quarries in the vicinity of this city are owned by A. Olson and Joseph Dean of Marshall. They are both located in sandstone of Coal Measure age. Both were worked quite extensively at one time, but at present they have been almost abandoned. Most of the stone now used in Marshall is shipped from Napton where quarries have been opened in the Burlington limestone.

THE DEAN QUARRY.

The Dean quarry is located five miles northwest of the city. It is said to produce a very good grade of sandstone, although it has not been very active for several years, the distance from the railroad practically prohibiting extensive development.

THE OLSON QUARRY.

This quarry, which is owned and operated by A. Olson, is located about two miles southeast of Marshall. It consists of two openings, one on each side of a ravine, about thirty feet from the bottom. The south opening extends about 200 feet along the hillside and has a depth of about 20 feet. The stone is covered with from five to fifteen feet of very tough clay stripping. Underneath the clay occur a number of well stratified beds of sandstone from four to eight inches in thickness. The lowest bed in the quarry consists of seven feet of massive sandstone, which, at the time the quarry was inspected, was covered with stripping which had washed into the quarry. Directly above this, occurs four feet of the best stone in the quarry.

The sandstone in this opening is fine grained and frequently stained with iron oxide. It is soft and friable when first quarried, but hardens upon exposure to the atmosphere. Some of the stone contains small pockets of loose white sand which quickly weathers out, leaving a pitted surface. If the stone is to be cut and dressed, care should be taken to select that which is free from these pockets.

The opening on the opposite side of the ravine, although smaller, contains stone similar to that just described, but of a somewhat inferior quality.

This quarry has produced a large quantity of stone, most of which has been used for foundations, bridge abutments and culverts. The

massive beds are well adapted to these uses and can be obtained in blocks of any desired dimensions. The stone from the upper beds has been used for caps, sills and door-steps. It is rather soft for steps, but is fairly well adapted for caps and sills. The abandonment of this quarry was chiefly due to the heavy stripping.

MIAMI.

One of the largest sandstone quarries operated in the State is located one and one-half miles west of Miami, where a heavy bed of Pennsylvanian (Coal Measure) sandstone has been extensively developed.

THE WHITE ROCK QUARRY.

The Carroll County Sandstone Company, by which this quarry is owned, is a corporation consisting of A. T. Kendrick, B. D. Kendrick, O. A. Kendrick and Wm. Bushy. The quarry was opened in 1868 and has been operated almost continuously ever since. The company owns 160 acres of land underlain by stone similar to that in the quarry, constituting an almost inexhaustible supply.

The face of the quarry is 1,200 feet long and 130 feet deep. The upper twenty feet is loess stripping, while the remaining one hundred and ten feet is a massive bed of sandstone. The upper thirty feet of this bed has a light buff color, due to disseminated particles of iron oxide and iron sulphide. The lower eighty feet has a white color, being essentially free from iron oxide and containing only an occasional nodule of iron sulphide.

The upper portion is softer than the lower, and owing to its variegated color, is used entirely for bridge abutments and other purposes in which color is not an important factor. The stone from the lower part of the quarry, being uniform in color and texture, is used very extensively for caps, sills, monument bases and dressed building stone.

As a whole, the stone consists of fine rounded grains of translucent quartz, cemented together chiefly with calcium carbonate. Small flakes of mica, grains of iron oxide and nodules of pyrites are lesser constituents of the rock. Large oval areas in the stone have been changed practically to a quartzite. These masses are known locally as "nigger heads," and are scattered irregularly through the quarry. They are too hard to be channeled and are usually removed by blasting. Occasionally these masses are ten feet long by four feet thick. Some of the stone contains carbonaceous material, in the form of very thin black layers having the appearance of long narrow leaves. As a rule, they occur parallel to the bedding planes and only show as a dark line, when the stone is cut normal

to the bedding. Occasionally, these layers occur in an inclined position, in which case they show as irregular dark spots on the face of the stone.

When first quarried, the stone is rather soft, but as in the case of most sandstones, it hardens with seasoning. An old face of the quarry, which has been exposed for twenty or twenty-five years, shows little or no effect of weathering. The surface has been discolored by surface water carrying clay, but there is no evidence of alteration in the stone. Only one or two unimportant joints occur in the quarry. Just north of the middle portion of the quarry, there is a joint which strikes N. 45° E.

The floor of the quarry consists of several feet of shale, underneath which occurs a twenty-eight inch seam of coal, which, in the spring of 1902, was being mined just north of the quarry. This coal seam is expected to provide all the fuel necessary to operate the machinery at the quarry.

The massive, homogeneous character of the stone permits of extensive quarrying operations with comparatively little waste. Mill blocks of any desired dimensions can be obtained, the size being limited only by the carrying capacity of the derricks. The quarry is equipped with modern machinery, including two steam channelers, gang-saws, engine, derricks, car tracks, etc. The quarry is operated eight months in the year and employs, on an average, twenty-five men. The stone can be worked into any desired shape and the company is prepared to furnish stone for the following purposes: Buildings (caps, sills, cornices, coursing and columns), hitching posts, stepping-blocks, monument bases, foundations, crosswalks, sidewalks, curbing, bridge abutments, and retaining walls. In both the sawed and rock-faced finish, the stone has a very pleasing appearance.

This sandstone has been used in the construction of the Iowa State Capitol, the Methodist church at Carrollton, the Public Library at Fulton, and for bridge abutments along the Wabash railroad. It has also been shipped to the following cities for miscellaneous uses: St. Joseph, St. Louis, Kansas City and Marysville, Missouri; Lincoln, Nebraska; Ottumwa, DesMoines, Atlantic, and Bloomfield, Iowa.

LABORATORY EXAMINATION.

Microscopic.—The examination of a thin section of this stone shows that it consists chiefly of roundish to subangular grains of quartz, with subordinate amounts of calcite, iron oxide, feldspar and clay. The quartz grains are cemented in places rather firmly with calcite and to a lesser degree with iron oxide and bitumen.

Physical Tests.—The following are the results of tests made upon two-inch cubes of this stone, to determine its strength and durability:

Crushing strength	7477.6 lbs. per sq. in. on beds.
	9203. lbs. per sq. in. on edge.
Transverse strength	1321.76 lbs. per sq. in.
Specific Gravity	2.637
Porosity	14.31 per cent.
Ratio of absorption	6.33
Weight per cubic foot	141.3 lbs.

Crushing strength of sample subjected to freezing test 8670.5 pounds per square inch.

Reviewing the above tests, our attention is called to the fact that in spite of the moderately high porosity, this stone did not apparently lose strength as a result of the freezing test.

MONTROSE.

THE MORRIS QUARRY.

This quarry, which is owned and operated by W. H. Morris, was opened about twenty-five years ago, but at present it is operated only intermittently.

The quarry is located three and one-half miles north of town and is situated on the west side of a ravine, along which the sandstone outcrops. The stone has been quarried into the hill about twenty feet and about one-fourth of a mile along the ravine.

The face consists of nine feet of sandstone, made up of the following beds from top to bottom:

3 ft.	Clay stripping.
3 ft.	Buff to gray sandstone, containing nodules of iron oxide.
1 ft. 6 in.	Fine grained, gray sandstone; the hardest in the quarry.
4 ft.	Fine grained, soft, gray sandstone, containing hard round nodules of ironstone. These nodules do not occur with any regularity, but are much more prevalent in some parts than in others.

Large roundish boulders of quartzite, which are too difficult to cut and dress to be used for building purposes, occur in the soil stripping. Below the floor of the quarry there is a bed of decomposed sandstone, in layers from four to eight inches thick. It contains iron oxide along the bedding planes.

The major jointing planes strike N. 60° E. The minor jointing planes strike east and west and N. 10-20° W. These joints are about twenty-five feet apart and are taken advantage of in working the quarry.

On the opposite side of the ravine, the sandstone outcrops in beds from two to six inches in thickness. These beds have been quarried to some extent for flagging, curbing, sills and steps. This stone is in all respects similar to that on the west side of the ravine, although the stripping is somewhat less.

The abutments for the bridge on the Missouri, Kansas and Texas

railroad, at Bear Creek, were constructed out of stone from the opening on the west side of the ravine.

LABORATORY TESTS.

The following are the results of tests made to determine the strength and durability of the stone from this quarry:

Crushing strength	5370.7 lbs. per sq. in.
Tensile strength	254.5 lbs. per sq. in.
Transverse strength	112.3 lbs. per sq. in.
Specific Gravity	2.699
Porosity	11.37 per cent.
Weight per cubic foot.....	128.7 lbs.

Crushing strength of sample subjected to the freezinz test, 2,858.5 pounds per square inch.

In the case of this stone, it is evident that the crushing strength was materially lowered as a result of the freezing test. An average of two tests on this stone on edge gave a crushing strength of 4,408 pounds per square inch, which is higher than the crushing strength of the frozen samples.

RICH HILL.

The Lower Coal Measure sandstone at Rich Hill supplies the local demand for stone used in rough masonry. Two quarries, located near the northern limits of the city, are owned and operated respectively by Robinson Bros. and Geo. Ames.

THE AMES QUARRY.

This quarry, which is owned and operated by Geo. Ames, is located between 5th and 6th streets, near the north end of Lashbrook avenue. It consists of a small irregular opening, in which the marketable stone is covered with from seven to eleven feet of clay and thin shelly sandstone. The workable beds are from six to eight inches in thickness and have a combined thickness of three feet.

The stone is very similar to that in the upper part of the quarry operated by Robinson Bros. It is rather soft when first quarried, but hardens upon exposure to the atmosphere. The excessive amount of stripping makes quarrying comparatively expensive.

THE ROBINSON QUARRY.

This quarry, which is operated by C. H. and E. E. Robinson, is located west of the Missouri Pacific railroad, between 6th and 7th streets, just north of Cedar street. It was opened in 1880 and has been worked intermittently since that time. It has been opened a distance of 240 feet

east and west and 150 feet north and south. The following is a description of the beds from top to bottom:

4-6 ft.	Thin beds interstratified with shale and sandstone.
8 ft.	Interstratified beds of shale and sandstone from two to four inches in thickness. The sandstone is fine grained and micaceous. Contains leaf-like impressions along bedding planes. Some of these beds are used for light flagging.
1 ft. 4 in.	Light buff to gray, fine grained, micaceous sandstone. Contains numerous stratification planes, on account of which it cannot be safely laid on edge in a wall.
10 in.	Very sandy shale.
2 ft. 3 in.	Fine grained micaceous sandstone impregnated with bitumen or asphalt. The stone is cross-bedded and shelly in places.
8 ft.	Massive, fine grained, dark colored sandstone impregnated with bitumen or asphalt.
3 ft.	Stone similar to the eight foot bed above.

The lower portion of the quarry was under water when visited.

The bitumen contained in the sandstone in the lower part of this quarry decreases the absorption and increases the strength, making the stone more desirable for places in which there is danger of injury from alternate freezing and thawing. The one foot four inch bed splits with a straight fracture and works well in the quarry.

The beds at the east end of the quarry dip N. E. 5°. Along the bedding planes, there are leaf-like impressions of carbonaceous material, similar to those observed in the Warrensburg quarries.

The quarry is equipped with a hand derrick and horse power pump.

WARRENSBURG.

Two of the largest sandstone quarries in Missouri are located at Warrensburg, Johnson county. The importance of these quarries is, in a large measure, attributable to the occurrence at this place of a considerable thickness of massive sandstone of Lower Coal Measure age. As a rule, the Lower Coal Measure formation consists of thin beds of alternating sandstone, limestone and shale. As a result, very few important quarries have been opened in this formation. The quarries at this place, and at Miami, are the only ones of any magnitude.

The sandstone at Warrensburg appears as a local thickening of the strata, following a sinuous north and south line. The deposit is narrow, thinning rapidly both to the east and west. Broadhead* believed this sandstone to be at the same horizon as that occurring at Miami and Butler, Missouri. Lithologically, the sandstones at these three localities are very similar. The Warrensburg and Miami stones are almost identical in composition, as will be seen by comparing their chemical analyses. The

*Missouri Geol. Sur. 1872, p. 42.

only detailed examination of this sandstone was made by Winslow in 1890 and 1891, in the preparation of the Higginsville sheet, which includes an area in Lafayette county just north of Warrensburg. The following extract from this report is the best explanation of the occurrence of the stone which has thus far been made:**

"The true stratigraphic and structural relations of this formation, however, seem not to have been recognized. It appears generally to have been considered of Lower Coal Measure age, and to have been correlated with the inter-stratified sandstones of the Lower Coal Measures, referred to on other pages of this report. The peculiar conditions of occurrence of this formation have, however, received no satisfactory explanation in print, to the writer's knowledge.†

The theory here advanced concerning this deposit is that it is of fluvial or lacustrine origin, that it fills a channel which was eroded in the surrounding, regularly deposited strata, during a temporary emergence of these strata from beneath the waters of the Coal Measure swamp. The leading reasons for this conclusion are briefly the following:

1. The great thickness of the deposit.
2. Its long and narrow shape.
3. The superposition of the sandstone upon the Middle Coal Measure rocks.
4. The inclusion of fragments of adjacent rocks."

This was one of the first stones to be extensively quarried in this State, and at one time constituted one of the principal building stones in St. Louis. A number of quarries were opened in this stone at an early day, but all except two have long since been abandoned. These quarries are owned and operated by Jacob Pickel of Warrensburg and Lawrence Bruce of St. Louis.

THE BRUCE QUARRY.

This quarry was opened in 1867 and since that time has been worked almost continuously. It is located in secs. 11 and 14, T. 46, R. 26 W., about two and one-half miles north of Warrensburg. The quarry has recently been leased to the Forrester Brothers Stone Co. of Kansas City. The opening farthest west has a vertical face of about 45 feet, which extends about 1,000 feet north and south. Just east of this, the second opening has been worked to about the same depth and about 300 feet

**Missouri Geol. Sur. Areal Geology, Vol. IX, p. 51.

†In a letter to the writer of February, 1890, Prof. Broadhead explains the peculiar altitude or position of the sandstone in Lafayette county as due to a bulging of the Lower Coal Measures, and this was probably the explanation accepted by the earlier surveys. In more recent writings, Prof. Broadhead abandons the older view in the light of this later acquired evidence.

north and south. An enormous amount of stone has been removed from these openings, neither of which is being worked at the present time. Quarrying is now being carried on exclusively at the new opening which is located northeast of the other two.

The stone in the abandoned openings is essentially a fine grained, micaceous sandstone, cemented with calcium carbonate and bitumen. Two-thirds of the stone is what is commonly known as blue, while the remainder is white. The blue sandstone occurs chiefly in the upper part of the quarry and the white at the bottom. Between the white and blue is a transitional zone in which the stone has a streaked or striped blue and white color. This striped appearance is due to alternating thin layers of blue and white stone. At the bottom of the quarry, the stone is again slightly blue and is known locally as "bottom blue."

Parallel to the bedding planes or at a slight angle occur leaf-like impressions of dark carbonaceous material. Where especially abundant, this material causes what is locally known as a "reedy" structure. Stone having this structure will separate easily along the planes of deposition of the carbonaceous material, greatly injuring its value.

The quarry contains occasional irregular, nodular areas in which the sandstone has been altered to quartzite. These are known by the quarrymen as "nigger heads." In places, the stone has been colored with concentric bands of iron oxide, forming what are known to the quarrymen as "kidneys." When some of these so-called "kidneys" are exposed to the atmosphere, the iron oxide washes out, staining the stone in their immediate vicinity. These "kidneys" occur chiefly in the blue stone, and they increase materially the percentage of waste. The blue stone contains occasional nodules of iron sluphide, while the white variety is free from this impurity.

Short discontinuous joints, which occur in the stone, are locally known as dries and slips. The dries are small jointing planes which have been discolored by iron oxide. They are usually vertical and continue only for a short distance. The slips are small discontinuous joints, generally inclined, which show no discoloration. In some parts of the old openings, these joints were a source of considerable annoyance. The new opening has been sunk only to the depth of two channel cuts, and it is impossible to say what the character of the stone will be below. One hundred feet west, the stone was tested by hand channeling and thirty-five feet of excellent blue stone was found. The stone was not prospected below this depth.

The quarry is equipped with all modern machinery, including a power plant, Wordwell channelers and steam derricks. Near Warrensburg,

WARRENSBURG SANDSTONE.
Pickel Bros. quarry, Warrensburg, Mo.

located upon a side track of the Missouri Pacific railroad leading to the quarry, the company has a mill in which the stone is sawed and dressed. The quarry is usually worked from March to December and employs twenty men, on an average.

Besides being used for all constructional purposes, the sandstone makes an excellent grindstone. The gray variety is coarse grained and quick cutting. The stone known as the "bottom blue," is finer grained and makes a better edging grindstone.

THE PICKEL QUARRY.

This quarry is located two miles directly north of Warrensburg, in the W. ½ of the S. W. ¼ of sec. 12, T. 46, R. 26 W. It is owned by Jacob Pickel and operated by his two sons, under the firm name of Pickel Bros. It has been in continuous operation since it was opened in 1873. It is worked from April to November and employs about fifteen men. Mr. Pickel owns two 80-acre tracts of land on each of which a quarry is located. The opening, which lies just west of the Bruce quarry, is not being operated. The stone is essentially the same as that obtained from the other opening to the east.

The active portion of the quarry consists of a rectangular opening 400 feet long by 200 feet wide by 55 feet deep. Stone is now being quarried from the east 200 feet of the south side of the quarry.

The stone is a fine grained. calcareous sandstone in which the quartz grains are cemented mainly with calcium carbonate. The stone has a light bluish gray color in the upper part of the quarry, gradually taking on a deeper blue tint, as the depth increases, to within eight feet of the bottom, where the color changes to white. The transition from blue to white is sharp and distinct. The twenty feet directly above the white is the best blue stone.

Small nodules of iron sulphide occur in the quarry, chiefly in the blue stone. They are distributed promiscuously, although they are more abundant at some horizons than at others. In some parts of the quarry they do not occur. A chalybeate spring occurs about fifteen or twenty feet from the base of the quarry, giving evidence of the quantity of iron in this formation, especially at that horizon.

Carbonaceous matter occurs in some parts of the quarry along the bedding planes. When the stone is split parallel to the bed, this appears as leaf-like impressions or sheets. When broken normal to the bedding, it is either not noticeable or has the appearance of black pencil marks. Stone, which contains an abundance of carbonaceous matter takes on a

"reedy" structure, which renders it unsuitable for building purposes. In some places the stone is apparently cross-bedded. Occasional pieces of coal occur in the stone.

As in the case of the Bruce quarry, one finds here large irregular masses of the sandstone which has been indurated so that it is now almost quartzite. These masses usually have a lighter color than the surrounding stone and are known by the quarrymen as "nigger heads." They are very detrimental and are usually removed by blasting.

When lifted in the quarry the stone has a tendency to break along the stratification planes, which dip slightly to the southwest. The stone is channeled from east to west and lifted to the south, in order to minimize the waste which results from this tendency to split along the stratification planes.

Near the surface the stone is soft and only used for foundation purposes. Deeper in the quarry it becomes gradually harder. The difference in hardness is nicely shown by the rapidity with which the stone is cut by the gang-saws. That from the surface is cut at a rate of from eight to ten inches per hour, while that from the lower portion is cut at a rate of from five to six inches per hour. The white stone is thought to be the best in the quarry and is particularly well fitted for buildings, in which it is used for caps, sills, steps, cornices, coursing and foundations. The stone is also used for sidewalks, monument bases, curbing, chimneys, hitching posts, stepping blocks, retaining walls and columns.

The quarry is equipped with modern machinery for quarrying, cutting and dressing the stone. Wordwell channelers, gang-saws, steam hoists, and steam derricks are among the equipment. The company is in position to supply either rough or sawed stone of any dimensions.

LABORATORY EXAMINATION.

Microscopic Examination.—A thin section of this stone, examined under the microscope, shows that it consists chiefly of small roundish to subangular grains of quartz with subordinate amounts of calcite, mica, chlorite, iron oxide, bitumen, feldspar and clay. The chief cementing constituents are calcite and iron oxide.

Physical Examination.—The following are the results of tests made on this stone to determine its strength and durability:

Crushing strength	5910.6 lbs. per sq. in.
Tranverse strength	777.97 lbs. per sq. in.
Specific Gravity	2.6485
Porosity	16.765 per cent.
Ratio of absorption	7.644 per cent.
Weight per cubic foot.....	137.7 lbs.

Crushing strength of sample subjected to freezing test, 5097.5 lbs. per sq. in.

WARRENSBURG SANDSTONE.
Johnson County Courthouse, Warrensburg, Mo.

The result of the average of three determinations of the crushing strength on edge gave 4,860 pounds per square inch. The crushing strength of this stone is not high, although sufficient for most buildings of ordinary dimensions. It is evident from these tests that the strength of the stone is affected very little by alternate freezing and thawing, although the impression seems to have prevailed that the stone does not withstand effectually conditions of alternate freezing and thawing.

The following is a partial list of the buildings in which the stone from this quarry has been used:

ST. LOUIS, MO.

Chamber of Commerce.	Leighton Building.
Southern Hotel.	Thompson Building.
Lindell Hotel.	Oliver Hart Building.
Beers Hotel.	Kennett Building.
St. Joseph Church.	Wilgas Building.
Second Baptist Church.	Murphy Building.
Union Methodist Church.	Gay Building.
Lucas Av. Pres. Church.	Granite Building.
Third Pres. Church.	Bradford & Martins.
Jesuit College.	Drummond Tobacco Works.
Gerhard B. Allen Residence.	Peter L. Foy Residence.
Major Pope Residence.	Ex. Governor Standard Residence.
Col. Hunter Residence.	Capt. White Residence.

OMAHA, NEB.

Y. M. C. A. Building.	Johnson Residence.
J. H. Green Building	Water Works.
Hayden Block Building.	Martin Building.
St. John's Church.	

KANSAS CITY, MO.

U. S. Postoffice.	Warder Grand Opera House.
Oglesby Building.	

LINCOLN, NEB.

Lincoln Normal University.	Lindell Hotel.
Union College.	Lyman Terrace.
Grant Memorial Laboratory of Nebraska.	

PUBLIC BUILDINGS.

Insane Asylum, Clarinda, Iowa.	Grand Hotel, Council Bluffs, Iowa.
Greenfield Court House, Iowa.	Maryville Court House, Kansas.
Red Oak Court House, Iowa.	Olathe Court House, Kansas.
Cherokee Court House, Iowa.	Ottawa Court House, Kansas.
Osceola Court House Iowa.	Lincoln Court House, Kansas.
David City Court House, Nebraska.	Clinton Court House, Missouri
Blair Court House, Nebraska.	Sedalia Court House, Missouri.

Natural Science Building, University of Illinois, Urbana, Ill. And numerous others.

CHAPTER X.

AREAS FROM WHICH STONE SUITABLE FOR DIFFERENT USES MAY BE OBTAINED.

It is impossible for a stone to possess all of those qualities which would make it suitable for all the different uses to which stone is put. The property known as cleavage, which makes a stone sometimes suitable for roofing slate, makes it unfit for use in the walls of a building. The different uses call for different properties, and a stone must be selected with respect to the purpose for which it is to be used. If greater attention were paid to the suitability of stone, used for different purposes, our buildings and other stone constructions would be far more permanent than they are today.

BUILDINGS.

The walls of a building consist chiefly of the foundation and superstructure. As a rule, that portion of the wall which is below the first floor is known as the foundation, and that above as the wall. A part of the foundation is usually concealed beneath the ground and this is commonly constructed out of random rubble masonry. The walls and that portion of the foundation which is above the ground are usually either ashlery or rubble masonry. Stone which is used in the exposed part of a building above ground should be carefully quarried, cut and dressed. The tendency now is to make the joints as small as possible, not exceeding one-fourth of an inch in thickness.

Stone which is used in a building should have a uniform color, and should be strong enough to support a weight from 10 to 20 times that of the superincumbent load when placed in the walls of a building. A stone should not discolor or fade and should possess a transverse strength which will insure its remaining perfect when used in the caps or sills of a building. If the stone is used in a position where it will be subject to the effects of alternate freezing and thawing, care should be taken to protect it from these agencies.

The granite which occurs in Madison, St. Francois, Iron, and the adjoining counties in Southeast Missouri, is undoubtedly the most desirable as well as the most durable stone which is quarried in Missouri

for this purpose. There is no part of a building in which this stone can not be used to advantage. Buildings which have been entirely constructed out of this stone, present a handsome, as well as a massive appearance. Its uniform color makes it especially desirable for interior or ornamental work. The stone can be obtained in blocks of almost any dimensions, limited only by transportation facilities. The red granite quarried by the Syenite Granite Company, Schneider Granite Company, Milne & Gordon, and others, is well adapted for all parts of a building in which stone other than slate can be used.

The rhyolite which occurs with the granite, in the same district, has practically the same quality as the granite when considered for building purposes. The rhyolite, however, occurs in small blocks, many of which are not of suitable size for buildings. The rhyolite varies in color from a gray to many shades of brown, purple and red. The stone is very strong and durable, but the expense of quarrying, cutting and dressing prevents its use in buildings or monuments. The limited extent to which the granite is used, is a result entirely of the cost of quarrying, cutting and dressing it.

The limestones and sandstones from all the formations have been used to some extent in buildings. A majority of the quarries in the sedimentary formations are engaged exclusively in producing stone to supply the local market. However, there are a number of localities in which extensive quarries have been opened and from which exceptionally good building stone is obtained.

The dolomites of the Cambro-Ordovician are used extensively throughout the southern part of the State for buildings. These formations outcrop everywhere along the hillsides of the Ozark plateau region. The stone belonging to a particular formation does not differ greatly in any part of the region. This being the condition, quarries have been opened in the vicinity of nearly every town to supply the stone needed by the local market. These quarries are not worked continuously and sometimes they remain untouched for several years. Most of them are worked without machinery, the stone being quarried from near the surface, where weathering has opened up the joints and bedding planes, breaking the stone into blocks which can be easily handled. These dolomites have been carefully described in the discussions of the various quarries, which occur in these formations.

The most extensive quarries in the Cambro-Ordovician formations are located at Jefferson City. At this place both the so-called cotton rock and the pitted dolomite are exploited. When freshly quarried and dressed, the cotton rock has a very pleasing light buff color and when carefully

selected may be used to advantage in buildings. In some localities, however, this stone is argillaceous and thinly stratified, on account of which it disintegrates somewhat rapidly when exposed to the atmosphere. The pitted dolomite occurs in thick, massive beds and constitutes a very desirable stone for heavy masonry. It has been used more extensively than the cotton rock, but owing to its massive character, is somewhat more expensive to quarry. This stone is only suitable for rock faced work. The small drusy cavities, with which it is filled, make it difficult to dress with a hammer, for the same reason it cannot be sawed or rubbed to advantage. In spite of the rough, pitted character of the rock, it constitutes a desirable building stone. Other quarries producing this stone are located at Rolla, Koeltztown, Eldon, Elston and Union.

In the southeastern part of the State, the formations which are of known Ordovician and Silurian age, contain limestones which are more finely crystalline and take on the character of marble. Some of the limestones of these formations have a variegated color and many of them contain pockets of clay which lessen their value as a building material. This marble, which occurs in Madison and neighboring counties, is not being quarried at the present time. However, large blocks can be obtained and, provided the waste in quarrying is not too great, they may some day be exploited for building purposes. Observations on the natural outcrops indicate that large blocks of excellent quality may be obtained, but the amount of waste which, apparently, it will be necessary to remove, may prevent profitable quarrying.

Very few of the thick beds of sandstone of the Cambro-Ordovician formations are quarried for building purposes. Most of the stone is too friable to be used in buildings. In the vicinity of Cole Camp, near St. Elizabeth, and at a number of other places, it is being used locally for buildings and curbing.

The Trenton or Kimmswick limestone, which belongs to the Ordovician system, takes on the characteristics of a marble in the vicinity of Ste. Genevieve, making a very excellent building stone. It is being quarried and used quite extensively for this purpose. The Normal school buildings at Ste. Genevieve have been constructed out of this stone. In the vicinity of St. Louis, the Trenton limestone is soft and does not make a desirable building stone.

The Plattin limestone which occurs underneath the Trenton or Kimmswick at Ste. Genevieve is hard and difficult to dress, and therefore cannot be placed upon the market at a price that will compete with the Kimmswick limestone. It is a good stone for foundations and has been quarried locally for rubble.

The Niagara limestone has been quarried at Kissinger, Bowling Green and several other localities, where it occurs in massive beds which can be quarried with a considerable degree of economy. This limestone does not have a very wide distribution in the State and the few quarries in which it is exploited are unimportant.

The Devonian rocks have a very limited surficial distribution and are relatively unimportant as producers of building stone. The stone from this system has been quarried chiefly to supply the local demands for foundations. The Lithographic limestone, which may be of Devonian age, is well developed in the vicinity of Louisiana where it is quarried for rubble. This limestone has a very pleasing light gray to white color and has a uniform fine grained texture. It usually occurs in blocks which are too small for buildings. The Vermicular sandstone, which may also be Devonian has, according to Prof. E. M. Shepard, been used quite extensively as a building stone in Greene county, especially for chimneys. This stone is rather soft when first quarried, but hardens upon exposure to the atmosphere. No large quarries have been developed in this formation.

The formations belonging to the Mississippian system (Lower Carboniferous) furnish by far the best limestone in the State for building purposes. The Chouteau, which is the lowest formation of this system, is relatively unimportant, being quarried for rough foundation work in a number of places in the vicinity of Sedalia. The Burlington formation furnishes the greatest amount of cut and sawed stone of any of the formations in Missouri. This stone has a very uniform light, almost white color, is strong and durable and is quarried in large dimensions. In the vicinity of Carthage, there are six quarries which are producing building stone in large quantities. Extensive quarries are also located at Phenix and Hannibal where the stone is quarried, cut and dressed in large quantities. The Burlington limestone has a very extensive surficial distribution in this State and the areas from which this stone might be quarried are not restricted to the localities which are being developed at the present time. Other quarries might be opened in the southwestern and central portions of the State, from which equally as good stone might be obtained. The distribution of this stone is shown on the geological map, to which the reader is referred. For detailed descriptions of the stone, reference should be made to the discussion of the quarries at Carthage, Hannibal and Phenix.

The St. Louis limestone which belongs to the Mississippian system (Lower Carboniferous), is quarried extensively in the vicinity of St. Louis. The stone is used chiefly for rough rubble masonry and prac-

tically all of the stone used for foundations in St. Louis is obtained from this formation. Very little of this stone is cut and dressed for buildings. At present the Stolle Stone Co. and the Hill-O'Mera Construction Co. are the only producers of cut stone from this formation in St. Louis.

The Pennsylvanian system (Upper Carboniferous), comprising in this State the Lower Coal Measures, or Missourian, and the Upper Coal Measures, or Des Moines, consists of a variety of sandstones and limestones which are being quarried at many places to supply the local demand for building stone. The Lower Coal Measures consist of a large percentage of shale and sandstone and produce a relatively small amount of limestone. The limestone beds are usually thin and unevenly bedded, although compact and hard. Some of these beds make excellent coursing stone, but a greater percentage is suitable only for rubble. The principal quarries exploiting stone from the Lower Coal Measures (Missourian), are located at Miami, Warrensburg, Butler, Clinton, Milan, Trenton, Lamar, Liberal and Rich Hill.

The most important sandstone quarries in the State occur in this formation and are located at Warrensburg and Miami. The sandstones at these two places are very similar. The formation in which the quarries are located is from 50 to 125 feet in thickness and affords an exceptionally good opportunity for quarrying. Large blocks of sandstone, of either a blue or white color, may be obtained from any of the quarries at these places. Some of the stone has a "reedy" structure on account of which care should be exercised in selecting that which is most durable. The sandstone from this formation is comparatively soft when first quarried and can be cut and dressed with comparative ease. The stone hardens upon exposure to the atmosphere. For a detailed description of this stone, the reader is referred to the discussion of the quarries at the localities above referred to.

The Upper Coal Measures (Des Moines), contain a greater percentage of limestone and a lesser percentage of sandstone than the Lower Coal Measures. The amount of sandstone quarried in this formation is very small and is used chiefly to supply the local demands in the localities where the quarries are located. The limestone in general is fine grained, compact and fossiliferous. The bedding planes are uneven and wavy and the stone often contains thin shaly parting planes along which it splits very readily. The quarries located in this formation produce excellent rubble stone for rough masonry and a small amount of coursing. In general, however, the limestone in this formation does not occur in such a manner as to warrant extensive quarrying. At Kansas City, there are many quarries from which the stone is used to supply the local market.

The so-called "building stone ledge," which in places has been stained a yellowish or brownish color, through decomposition, is used for rustic rubble masonry. When used in this way, it has a very pleasing appearance. The principal quarries in this formation are located at Kansas City, St. Joseph, Amazonia, Jameson, Breckenridge, Parkville, Savannah, Plattsburg and Bethany.

In certain localities in the northern part of the State there are numerous glacial boulders of granite and other igneous rocks in sufficient quantity to be used for building purposes. These boulders are very durable and when used in random rubble masonry, their variegated colors produce unique and pleasing effects.

MONUMENTS.

The red granite of southeastern Missouri is the most desirable monumental stone quarried in the State. This granite has a remarkably uniform color and can be obtained in blocks of almost any desired size. It takes an excellent and lasting polish and must be regarded as one of the handsomest and best monumental and ornamental stones in the country. The quarries now being operated are located chiefly in the vicinity of Graniteville and Syenite. The individual quarries are described in the foregoing pages of this report, to which the reader is referred.

This granite might be developed much more extensively than it is at the present time. There are many inviting localities for the opening up of quarries and it is expected that, eventually, this stone will be used much more widely than now.

Among the limestones, that which is quarried at Carthage is the most desirable for monumental purposes. It has a uniform color, takes a good polish and when free from suture joints is a very durable limestone. Next to the granite, it is undoubtedly the best monumental stone in the State. It is especially adapted for the construction of mausoleums.

Marble, which takes a good polish and often has a beautifully variegated color, occurs in Madison and other southeastern counties. These deposits are not being developed at the present time. They are frequently overlain with heavy stripping and contain an occasional clay pocket which makes profitable quarrying somewhat questionable.

The Pennsylvanian sandstones, which are quarried at Warrensburg and Miami, are used quite extensively for monument bases. The stone at these places has a very good color and can be used to advantage in connection with both the red and gray granites. The J. T. Day quarry at Butler, Missouri, is operated almost exclusively for monument bases.

In southern Missouri, there are large deposits of onyx in the caves

of the Cambro-Ordovician formations. Many of these caves are located some distance from the railroads, which has operated against their development. The onyx varies from a pure white to a deep brown, and is frequently mottled. It is rather porous and the deposits which have been worked have been abandoned for this reason. Extensive deposits may occur which are solid and suitable for decorative purposes. At present none of these deposits are being worked.

BRIDGE ABUTMENTS AND CULVERTS.

In the selection of stone used for the construction of bridge abutments, durability is the chief consideration. Uniformity in color is a desirable feature, but is not important. Stone used for this purpose should be heavily bedded, homogeneous and free from stratification planes or other imperfections which weaken the stone. For railroad work, a maximum thickness of 2 feet is required. Although expensive, the red granite in the southeastern part of the State is the most desirable stone for this purpose. It is especially suitable for use at the water line where the action of water and ice is liable to cause rapid disintegration. In this part of the abutments of the Eads bridge at St. Louis, granite has been used. The quarries from which granite may be obtained for this purpose are located at or near Knob Lick and Graniteville and are described in the preceding pages of this report.

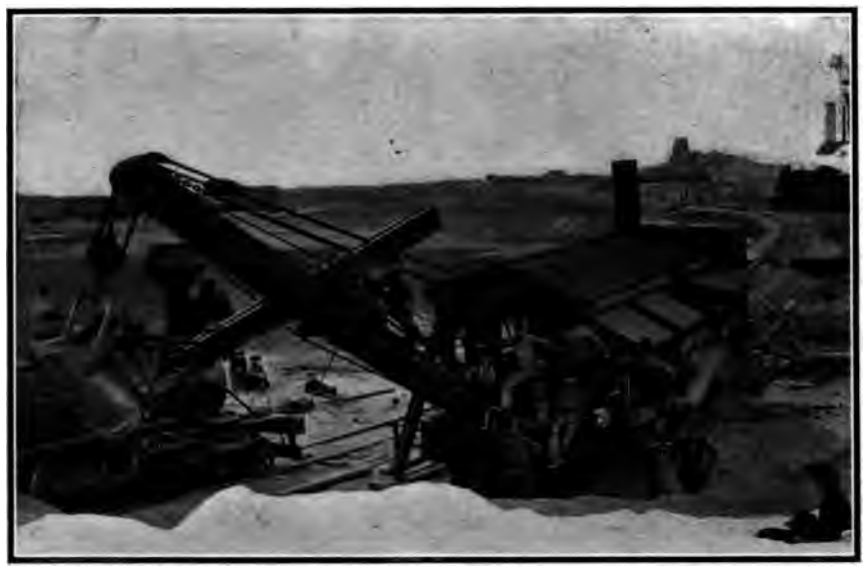
The heavily bedded dolomite occurring in the Cambro-Ordovician formations have been used extensively for railroad bridge abutments throughout the southern part of the State. In most cases, they have proven very durable. The cotton rock of these formations is not desirable on account of its tendency to disintegrate when exposed to the weather. The Aux Vasse sandstone, which was quarried south of Ste. Genevieve, was used extensively in bridge abutments. This stone was used in the upper part of the abutments of the Eads bridge at St. Louis. In the quarry, the beds show occasional fine stratification planes, on account of which some of the stone is undesirable for this purpose. It should be carefully selected.

The Burlington limestone, which is quarried at Carthage, Phenix and Hannibal, is very desirable for this purpose, when free from coarse suture joints. Practically the first stone quarried in the Carthage area was used by the Missouri Pacific railroad for bridge abutments. This stone is still perfect, showing very little evidence of deterioration.

The Mississippian limestone is quarried quite extensively at Noel for bridge abutments. A number of the beds show thin stratification planes which might be injurious if the stone were used in a climate where

CHAT PILE, JOHN JACKSON MINE, JOPLIN, MO.
Material for Railroad Ballast, Macadam and Artificial Stone.

1.



2.

CHAT PILES.

Fig. 1. Loading by hand.
Fig. 2. Loading by steam shovel.

alternate freezing and thawing is common. However, most of the stone from these quarries is used in the south where the climate is mild. The Warrensburg, Miami, and Liberal sandstones are used to some extent for bridge abutments. Some of the stone quarried at these places is suitable for this purpose, but that which has the so-called "reedy" structure is not desirable.

The thick beds of the Bethany Falls limestone, which is the basal member of the Upper Coal Measures, have been used for railroad bridge abutments. At Princeton, the beds are from 2 to 4 feet in thickness and the stone is well adapted for this purpose. It has been used extensively by the Rock Island railroad, and has proven to be one of the best stones for bridge abutments in northern Missouri.

Much of the Coal Measure limestone contains fine stratification or parting planes which in time will open up and cause the stone to disintegrate. Before being used, the stone from this system should be carefully selected in order to avoid defective blocks.

What has been said concerning the stone suitable for bridge abutments holds good in the case of culverts. Coal Measure limestone suitable for this purpose was observed at a number of localities in northern Missouri. Too great care cannot be exercised in the selection of stone for these purposes.

CURBING AND FLAGGING.

Probably stone is nowhere liable to greater injury from abrasion or freezing and thawing than when used for curbing, sidewalks and crosswalks. The fact that curbing stone must be set on edge renders it imperative that the stone should be free from bedding planes. Wherever these are present, they will eventually open up, causing the stone to flake. Where flagging is used for sidewalks and crosswalks, it is apt to become saturated with water with the attendant liability to disintegrate through alternate freezing and thawing. Flagging and curbing should have a capacity to effectually resist abrasion. This, however, does not receive adequate consideration and as a result there is probably no use, to which stone is put, which shows a greater want of judgment in its selection.

The red granite is the best stone quarried in this state, both for curbing, sidewalks, crosswalks, and steps. This stone is coarse to medium grained, hard and strong, possessing all the qualities which make it suitable for these uses. It seldom becomes slippery and is strong enough to withstand the weight of heavy loads. Granite is more costly than either limestone or sandstone, but its greater durability makes it less expensive

in the long run. The Missouri red granite is more durable than that from Georgia, although the latter, on account of its less cost, is used extensively in St. Louis. The schistose or laminated structure of the Georgia granite renders it more susceptible to disintegration than the Missouri product.

The pitted dolomite of the Cambro-Ordovician system, when it occurs in thin beds, is frequently used for curbing, sidewalks and crosswalks. It usually has a rather rough surface, but this does not materially injure the stone for these uses.

The Hannibal formation, quarried near Springfield at the Hollman quarry, has been used quite extensively for these purposes. It is an excellent stone for curbing and has proven very durable.

The Burlington limestone has been used very extensively for these purposes. It is quarried chiefly in the vicinity of Carthage, Phenix, and Hannibal, large quantities of the stone being produced at all of these places. These quarries have been described in the preceding pages of this report. It is sufficient to say that the stone has a uniform, white color, a homogeneous texture, and is not slippery when used for sidewalks.

The St. Louis limestone has been quarried and used in the vicinity of St. Louis for curbing and sidewalks. Some of the beds in this formation are well adapted to these uses, but, as a whole, the stone is not suitable either for curbing or sidewalks.

The Coal Measure sandstones, which are quarried at Warrensburg, Miami, and Liberal, are used to some extent both for curbing and sidewalks. These sandstones are rather soft and wear more rapidly than the limestones and granites previously referred to. The asphaltic sandstone, which is quarried at Liberal, has a higher crushing strength and less absorption than the average sandstone. It is probably one of the best sandstones quarried in this State for flagging and sidewalks. Sandstone has the advantage of not becoming slippery, although it is liable to wear unevenly. As a rule, it does not possess sufficient strength to make a desirable curbing stone.

Isolated beds of limestone occur throughout the Carboniferous system which are well adapted to these uses. A great part of the limestone contains thin stratification planes, on account of which it is unfit for curbing and sidewalks. The lower two feet of the so-called "building ledge" in the quarries at Kansas City contains fine stratification planes which make the stone unsuitable for curbing or sidewalks. This stone, however, has been used extensively for both of these purposes. As a result, much of the curbing is now in a very dilapidated condition.

PAVING BLOCKS.

Stone used for this purpose should, above all, have a capacity to resist abrasion. It should also wear evenly and not become slippery with age. The granite and rhyolite which occur in the southeastern part of the State are the only stones which are well adapted to this use. The rhyolite becomes very smooth and slippery and for this reason is less desirable than the granite. On account of this tendency, the rhyolite blocks are not, at present, being used extensively for paving. Millions of blocks of both porphyry and granite have been used in St. Louis and it is thought that the Missouri granite is equally as desirable as that obtained elsewhere, and for this reason should be used in preference to that from other states.

Both the sandstones and limestones in this State are too soft for paving blocks. The St. Louis limestone has been used to some extent, in St. Louis, for block paving, but it is too soft for this purpose and should be rejected in favor of the granite.

CRUSHED STONE.

The many uses to which crushed stone is put, together with the increasing demand, makes this one of the most important branches of the stone industry in Missouri. The different uses for crushed stone call for some variation in the properties of the stone.

The stone used for macadam should first have a capacity to resist abrasion and second that quality by which the particles will be bonded together when rolled. In crushed stone used for railroad ballast it is not required that either of these qualities be developed to a very high degree. The stone, however, should be sufficiently strong and durable to withstand alternate freezing and thawing without disintegration. Stone which is used for concrete should break with a rough surface, in order that the cement may be attached more firmly to the fragments. Crushed stone which is used in the manufacture of granitoid sidewalks, should have a high capacity to resist abrasion.

The granite and rhyolite of southeastern Missouri are the best stones in the State for macadam. When used as a top dressing to limestone macadam, the granite provides an excellent wearing surface which will last indefinitely if properly cared for.

Most of the dolomites of the Cambro-Ordovician system are too soft to make a desirable road metal. The chert or flint is better adapted to this purpose, although it lacks the cementing or bonding quality. The two might be mixed and used together to produce an excellent pavement.

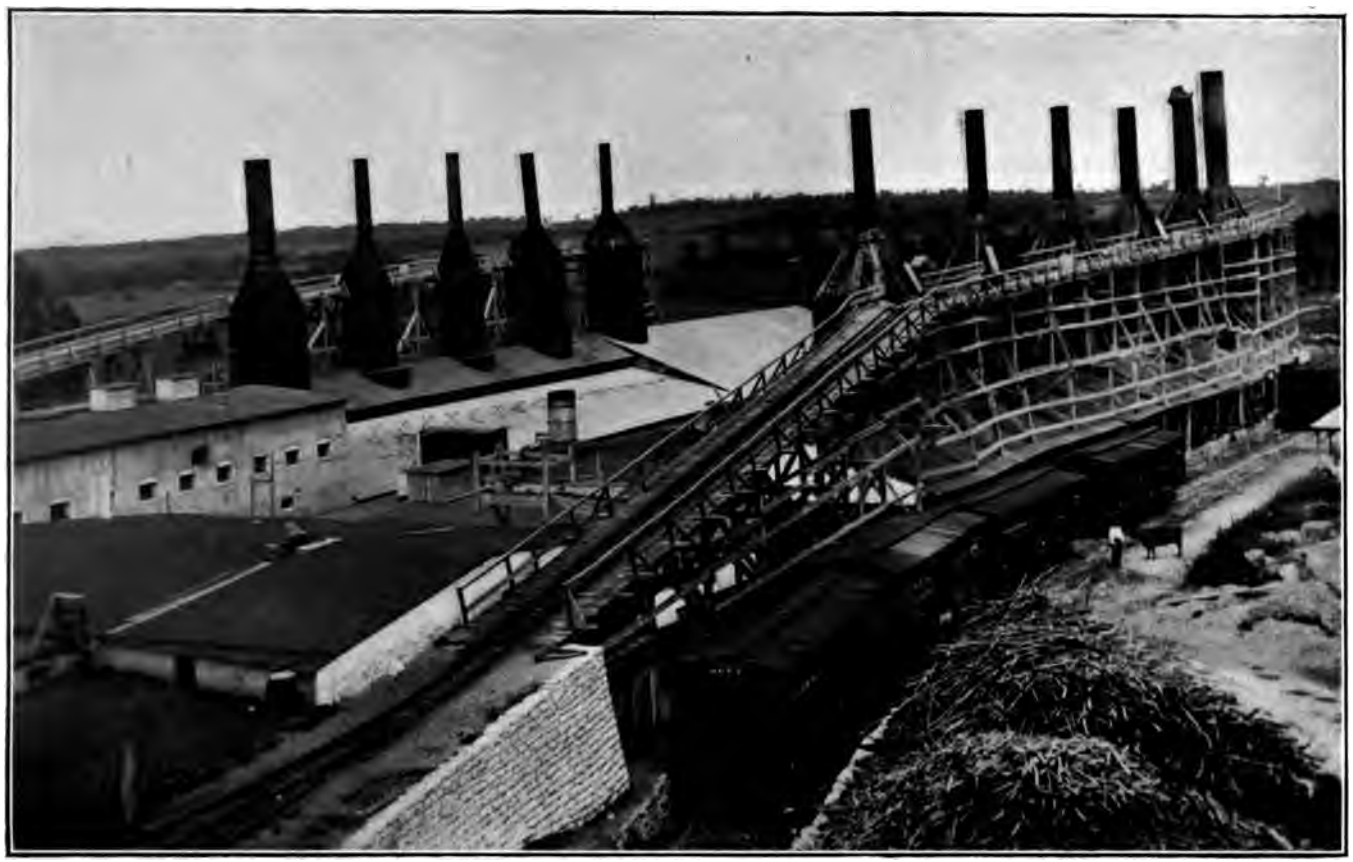
The Plattin limestone, in southeastern Missouri, is one of the best limestones in the State for road metal. It is used very extensively for railroad ballast and is an excellent stone for this purpose.

The Trenton limestone is in most places where quarried too soft to be used as a road metal. It breaks with a rough surface and is an excellent stone for concrete. This stone is being used extensively in the construction of the railroad bridge at Thebes, Illinois, being selected in preference to the Plattin limestone on account of its rough surface when crushed. The Bainbridge and Bailey limestones which outcrop between Cape Girardeau and Ste. Genevieve are among the best limestones in this State for ballast and road metal.

Most of the Burlington limestone is coarsely crystalline and unsuitable for road metal. Some of the limestone of the Lower Burlington in Greene county and elsewhere is finely crystalline and compact and might be used locally for macadam. At Sedalia this limestone, together with the Chouteau, has been used in the lower courses of the street pavements, the surface consisting of river gravel. This combination has resulted in a very excellent pavement for light teaming.

The St. Louis limestone has been used very extensively both for concrete and macadam. In general, it is too soft for macadam, although it constitutes a very desirable stone for concrete.

The sandstone of the Pennsylvanian system (Upper Carboniferous) is too soft for road metal. Much of the limestone is fine grained and compact and might be used in the construction of macadam pavements. However, in the larger cities, this stone should not be used except in the foundation courses. A macadam pavement should always be surfaced with granite or other stone equally as durable. At Kansas City, St. Joseph, Jameson, Parkville, Blackwater and Amazonia, the Coal Measure limestone is being crushed for railroad ballast, street paving and concrete. For more detailed information relative to the quarries in the vicinity of these cities the reader is referred to the preceding pages of this report. In the southeastern and southwestern parts of the State, the tailings (chats) from the lead and zinc mills are used very extensively for railroad ballast and paving. Hundreds of thousands of yards of chat are used annually by the railroads. In the Joplin-Carthage-Aurora district, the chats consist chiefly of flint with lesser amounts of limestone. This makes an excellent combination for macadam roads and should be used more extensively throughout the State. Millions of tons may be obtained in the southeastern and southwestern mining districts, with very little cost above that of transportation.



LIME INDUSTRY.
View showing kilns of the Ash Grove White Lime Association, Ash Grove, Mo.

RIVER AND HARBOR CONSTRUCTIONS.

Great quantities of limestone are used annually by the United States government in the construction of cribs, break waters, etc., along the Mississippi and Missouri rivers. Stone used for these purposes should be hard and durable having a capacity to resist erosion by the water. The best limestone in the State for these purposes occurs along the Mississippi river and is easily accessible. The United States government now operates a quarry at Little Rock Landing, near Ste. Genevieve, from which 87,416 cubic yards of rip rap was quarried in 1903.

QUICKLIME.

During 1903 Missouri produced over 1,000,000 barrels of quicklime, most of which was manufactured out of limestone belonging to the Burlington and Trenton formations. Both of these limestones are exceptionally pure, containing from 98 to 99½ per cent. calcium carbonate.

The greatest quantity of quicklime is produced from the Burlington limestone. All of this lime is white and of excellent quality. The Trenton limestone in the vicinity of St. Louis burns to a dark colored lime, which is very strong, but on account of its color, cannot be used for finishing work. This same limestone at Cape Girardeau makes a white lime of excellent quality.

The oölitic beds of the St. Louis limestone at Ste. Genevieve are used in the manufacture of quicklime.

Many other beds of limestone in the Carboniferous system have been used locally for the manufacture of quicklime, although they contain impurities which render the product inferior.

The dolomite of the Cambro-Ordovician system is used, locally, in many places for the manufacture of quicklime, which is said to be very strong. At Jefferson City, two companies are manufacturing quicklime out of this dolomite to supply the local market.

The subject of quicklime will be discussed in detail in a subsequent report which is now being prepared by this Bureau.

CEMENT.

The American manufacturers require limestone containing less than 5 per cent. magnesia for the manufacture of a high grade Portland cement. The Kimmswick (Trenton), Burlington, Lithographic and certain beds of the St. Louis formation consist of limestone which meets this requirement. Two extensive cement factories are in operation in this State, one at St. Louis and another at Hannibal. A third cement factory is being erected at Louisiana.

This industry will be considered in detail in a subsequent report.

FILTERS AND GLASS SAND.

The Pacific sandstone of the Cambro-Ordovician system, where essentially free from iron, is admirably adapted to the manufacture of glass. This sandstone outcrops extensively in the eastern part of the State, being quarried at Crystal City, Pacific, Grays Summit and Klondike. This sandstone is very friable and easily quarried and prepared for use. The sand is used for many other purposes besides the manufacture of glass.

The Newton county tripoli, which is a very porous, decomposed chert, is used very extensively for the manufacture of filters. Extensive deposits have been opened and there are now three companies operating in the vicinity of Seneca. A large part of the product is used for purposes other than filters.

MISCELLANEOUS USES.

The Lithographic limestone, occurring in the vicinity of Louisiana, has many characteristics of stone used for lithographing. Small blocks of this stone have been obtained which were well adapted for this purpose. The stone, however, is not sufficiently uniform in composition and texture to constitute a valuable source of this material.

The sandstone at Warrensburg has been used in the manufacture of grindstones and whetstones. It is a very quick cutting stone and when carefully selected appears to be well adapted to this use. A number of the Carboniferous sandstones might be used for this purpose, although they are somewhat soft and wear rapidly.

RÉSUMÉ.

Missouri is well supplied with excellent stone suitable for most constructional purposes. The red granite from the southeastern part of the State has a national reputation, while the limestone and sandstone have an extensive market throughout the central and south central parts of the United States. It costs more to quarry, cut and dress the Missouri limestone, but it is interesting to note that in spite of this fact it is taking precedence over the cheaper stones, which are being so widely advertised throughout the Mississippi valley. Preference is given Missouri limestone, simply as a result of its superior quality.

In this brief chapter, it has been impossible to refer to all the individual quarries from which desirable stone might be obtained. It has only been intended to indicate, in a general way, the adaptability of the stone belonging to the different formations to different uses. For a detailed description of individual quarries, or districts, the reader is referred to the preceding chapters of this report.

BURLINGTON LIMESTONE.
View of quarry of the Ash Grove White Lime Association, Ash Grove, Mo.

CHAPTER XI.

DISCUSSION OF THE RESULTS OF THE LABORATORY TESTS.

The strength and durability of a stone may be estimated in the laboratory by an examination of carefully selected samples. A chemical analysis may be made and from this, one may ascertain the presence of deleterious constituents and determine with a considerable degree of accuracy the mineralogical composition of the stone. One who understands the use of a microscope in the examination of rocks, may learn a great deal about the strength and durability through an examination of thin sections. Again, the strength and durability may be estimated by performing a series of physical tests in which the crushing strength, transverse strength, tensile strength, specific gravity, porosity, effect of alternate freezing and thawing and the effect of sulphurous acid gas are determined quantitatively. These determinations are usually made on two-inch cubes according to the methods described in Chapter III of this report.

Chemical analyses have been made of the stone from a number of the important quarries in this State and the results will be found in Table I of this chapter. Thin sections of a number of the important building stones were also prepared and examined under the microscope. The results of these examinations have been embodied in the text of the report, but will be discussed in brief in another part of this chapter. Complete tabulated results of the physical tests will be found in the latter part of this chapter. These tests have been referred to in the descriptions of the individual quarries, but will be discussed somewhat at length in this chapter. Table XI. gives the results of tests on stone from quarries in other parts of the United States. This is intended for the purpose of comparison with tests on stone from this State.

The tests on samples of sandstone or limestone from different parts of a quarry may give very different results. Sometimes they are more widely at variance than are the results of tests on samples from different quarries in the same area. Selected samples from a quarry may give very satisfactory results, while the stone as a whole, may be very inferior. Re-

sults which have been obtained for fair average samples are most valuable. The endeavor has been to make the results of the tests on stone from the quarries in this State represent as nearly as possible the average number one stone as it is sold in the market.

The value of the tests published in some reports on Building Stones is very little, owing to the inaccurate methods employed in making tests. In performing the tests recorded in this report, the endeavor has been to eliminate as far as possible everything, both in manipulation and computation, which may vitiate the results. It is believed that they are as nearly accurate as possible for the samples tested.

CHEMICAL ANALYSES.

The stone from seventeen different limestone quarries and three different sandstone quarries was analyzed to determine its composition and to detect such impurities as might occur. These analyses are given in Table I. in the latter part of this chapter. It will be observed that a greater part of the stone contains very little magnesium carbonate. The calcium carbonate ranges from 8.41 per cent. in one of the sandstones to 99.34 in one of the limestones. The magnesium carbonate ranges from .025 per cent. in stone from the quarry of the Republic White Lime Co., to 39.99 per cent. in stone from the Frech quarry at DeSoto. The stone from the quarries of the Carthage area, Hannibal Lime Co., the Halliwell Cement Co., the Phenix Stone and Lime Co., the Fullerton Quarry, the Denton Quarry and the Stolle Stone Co., all contain 96 per cent. or more of calcium carbonate.

A better understanding of the chemical composition of these rocks can be had by reference to Table I. In none of the samples analyzed was there any specially harmful constituent found.

THE MICROSCOPIC EXAMINATION OF THIN SECTIONS.

Thin sections were made of the stone from the more important limestone, sandstone and granite quarries and examined under the microscope. The results of these examinations are embodied in the text of the report under the descriptions of the quarries. As has been stated in another chapter, it is thought that one who has had experience can determine, with a remarkable degree of accuracy, the strength and durability of a stone, simply from an examination of thin sections under a microscope. By this means, one can detect the presence of detrimental constituents, such as iron sulphide. He can also estimate the strength from the mineralogical composition and texture, both of which may be determined through the microscopic examination.

PIECES USED IN MAKING THE PHYSICAL TESTS.

Plates LIII. and LIV. are Microphotographs of thin sections of granite, rhyolite, limestone and sandstone. From these one can learn a great deal about the size and manner of contact of the individual constituents of the more important kinds of rock.

STRENGTH TESTS.

Crushing strength tests were made on stone from most of the important quarries. Transverse strength tests were made on stone from twenty-one quarries, while tensile strength tests were made on stone from nineteen quarries. The method of performing these tests has been described in Chapter III. of this report. All of these tests are valuable to architects and builders, although to some, they are less significant than the tests intended to show the durability of the stone. Table VI. is arranged to show the relation between the crushing, cross breaking and tensile strength of the different stones tested. It is interesting to note that, as a rule, the stone having the highest average crushing strength also has the highest transverse and tensile strength. This is not the invariable rule, but the tendency is in this direction. The accompanying diagram shows the concordance of results as obtained for tests on nineteen different pieces of stone. The upper line is the crushing strength and the next is the transverse strength and the last the tensile strength. Each of the results represented in Table VI. is an average of from three to seven tests. The correspondence between the transverse and tensile strength is closer than between the crushing strength and either of the other two.

CRUSHING STRENGTH.

The crushing strength test has been relied upon by architects and builders, more than any other, as a basis for estimating the suitability of a stone for buildings and other constructions. The value of this test has probably been over estimated, although it is thought that this determination is important, especially in estimating the effect of freezing and thawing. One can only determine the loss in strength due to freezing and thawing when there is at hand reliable crushing strength tests of both the fresh and frozen samples.

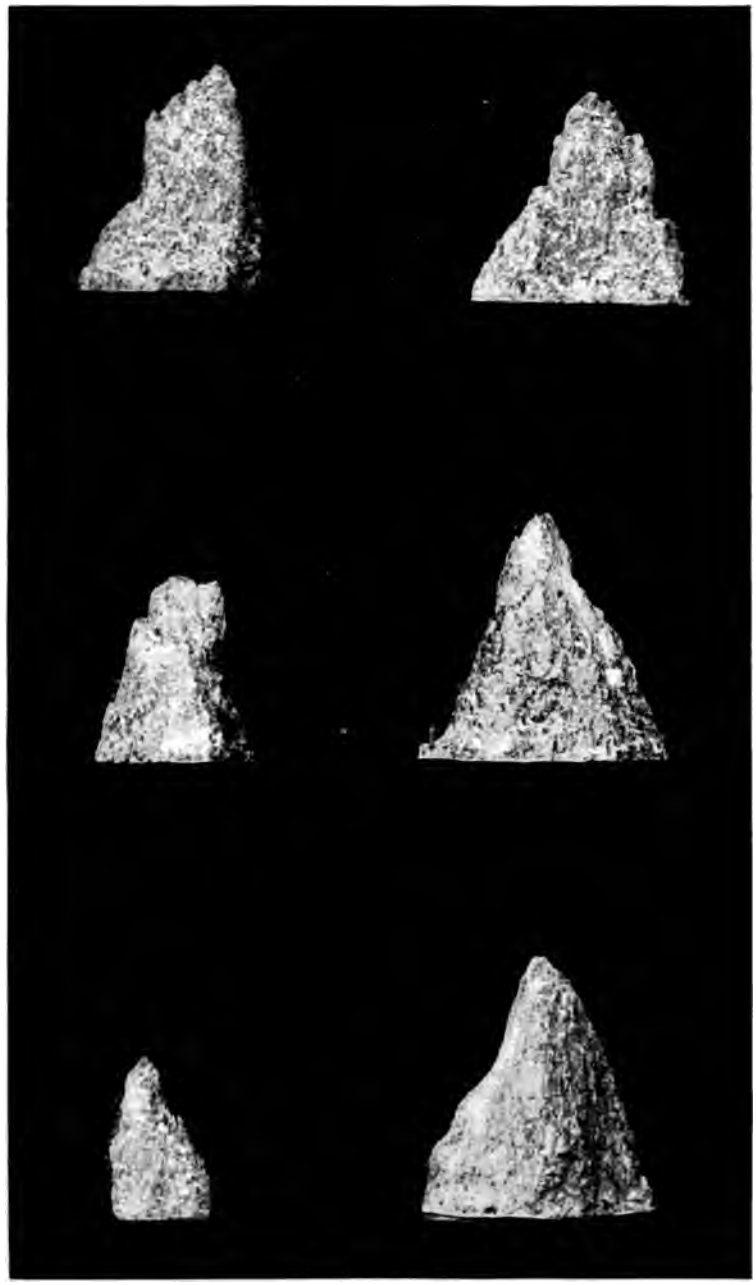
If it were only for the purpose of determining the strength of the stone, this test might in many instances be omitted, because it is well known that a stone having a crushing strength of over 5,000 pounds per square inch is strong enough for any modern structure. This may be changed when the results of intermittent and long continued stresses on stone are better known.

The crushing strength of the more important building stones in Missouri is given in Table III., at the close of this chapter. These tests

were made on three different testing machines and, as far as can be judged, they approximately agree with one another. The first part of the table gives the results of the tests on two-inch cubes of limestone; the second part gives the results of tests on two-inch cubes of sandstone; and the third part gives the results of tests on two-inch cubes of granite. This table gives the name and location of the quarry; the position of the sample in the machine; the average area of the bearing faces; the maximum crushing strength; the number of tests; and the average crushing strength in pounds per square inch.

Limestone.—Between one hundred and seventy-five and two hundred two-inch cubes of limestone, from twenty-one quarries, were used in making the crushing strength tests. From four to twenty-three cubes were tested from each quarry, part on bed and part on edge. The limestones show crushing strengths, ranging from 5,714 pounds per square inch to 27,183 pounds per square inch on bed and from 5,774 pounds per square inch to 25,577 pounds per square inch on edge. These results indicate that the stone from all the quarries is sufficiently strong to sustain any load which may be placed upon it in any of the larger buildings in the country. Of course, the higher the crushing strength, the greater is the limit of safety, but among all these tests none fell below the limit of safety for most large buildings, which is 5,000 pounds per square inch.

Attention is called to the crushing strength of the Carthage limestone which for a series of three tests on bed gave an average crushing strength of 17,777 pounds per square inch; one piece gave a result of 20,261 pounds per square inch. These results are interesting when compared with the tests on limestone from Bedford, Indiana. In the report of the State Geologist of Indiana for 1896, page 317, there is a record of tests on seventeen cubes of Bedford oölitic limestone, which gave an average crushing strength of 4,326.70 pounds per square inch. On page 313 of the same report, there is recorded a test on limestone from Salem, Indiana, which has a crushing strength of 11,700 pounds per square inch. From the tests made in the preparation of this report, it is evident that the Carthage limestone is about three times as strong as that from Bedford, Indiana. Attention is also called to the high crushing strength of the limestone from Kesterson's quarry at Jackson, and that from the Hughes Stone Co.'s quarry at Noel. The average crushing strength on bed of the former is over 27,000 pounds per square inch, while that of the latter is over 24,500 pounds per square inch. The crushing strength of the limestone from both the Phenix Stone and Lime Co.'s quarry and the quarry of the Pierce City Building Stone Co. is



GRANITE.

Pyramids resulting from crushing two-inch cubes of red and gray Missouri granite.

twice that of the Bedford limestone. The crushing strength of the limestone from Hollman's quarry at Springfield is very high, being over 20,700 pounds per square inch on bed.

Altogether these tests show a wide distribution of limestone having a crushing strength sufficiently high to permit its use in the largest of our public buildings.

Sandstone.—Forty-one two-inch cubes of sandstone were tested from five different quarries. The stone was tested both on bed and edge. In only one instance were the results higher on edge than on bed. These tests show an average crushing strength on bed ranging from 4,371 pounds per square inch to 9,002 pounds per square inch, and an average crushing strength on edge ranging from 3,933 pounds per square inch to 9,206 pounds per square inch. The highest results were obtained from samples from the Carroll County Sandstone Co.'s quarry. This stone gave an average result of 7,478 pounds per square inch on bed and 9,206 pounds per square inch on edge. The next highest results were obtained for the asphaltic sandstone from the quarry of the Liberal Stone and Coal Co. Samples of this stone tested 9,002 pounds per square inch on bed and 6,872 pounds per square inch on edge. Buff sandstone from the same formation from which the asphaltic sandstone is quarried gave an average crushing strength of 4,371 pounds per square inch on bed and 3,933 pounds per square inch on edge. These results show clearly that the asphalt or bitumen which impregnates the sandstone increases its strength. The average crushing strength of the stone from most of these quarries is above that required for most public buildings. However, some of the stone is not strong and should only be used in positions where the load is relatively light.

The pieces broke quietly, resulting in the formation of one and sometimes two fairly good pyramids. Apparently the perfection of the pyramids increases with a decrease in the crushing strength.

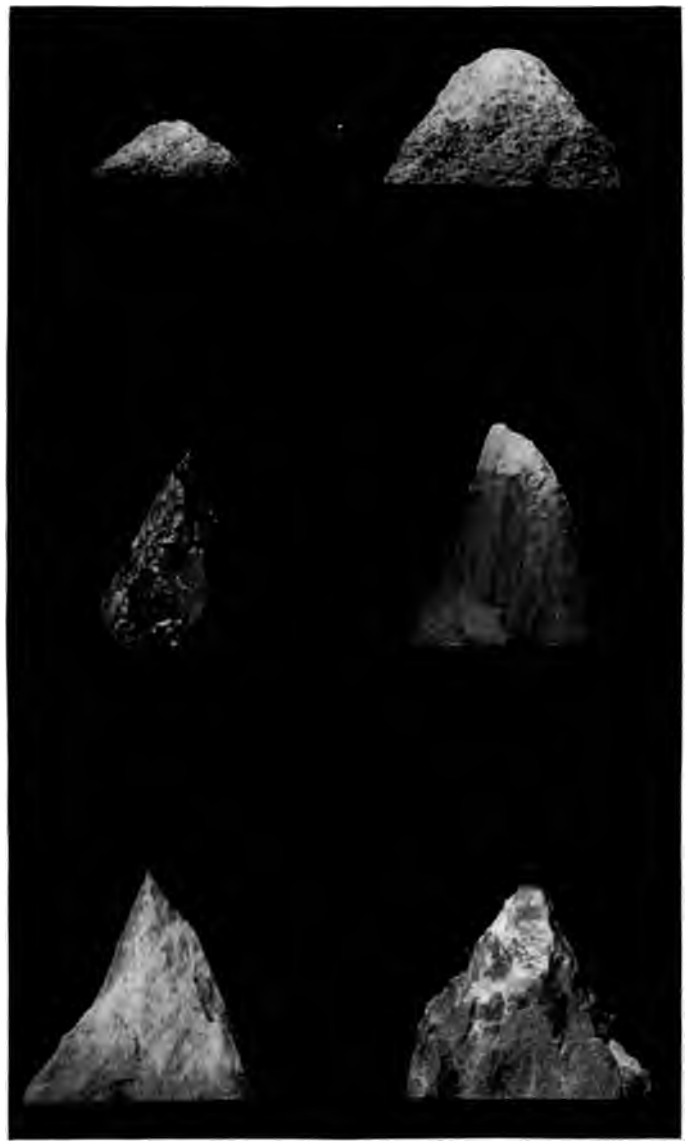
Granite.—Twenty-eight two-inch cubes of granite from three quarries were tested to determine their crushing strength. Twenty-one of these cubes were red granite and seven gray granite. Unfortunately the cubes were poorly made and imperfect. This resulted in giving a crushing strength considerably below what it should be. The maximum crushing strength obtained for the red granite was 31,550 pounds per square inch and the average of eleven cubes was 22,883 pounds per square inch. Ten cubes of red granite from another quarry gave a maximum crushing strength of 23,726 pounds per square inch and an average of 19,410 pounds per square inch. Seven cubes of gray granite gave a maximum crushing strength of 23,703 pounds per square inch and an average

crushing strength of 18,236 pounds per square inch. The average strength of the pieces tested is far above that required of any stone used in the largest buildings now constructed. A higher crushing strength than is here recorded is unnecessary to support the heaviest wall in which stone is used.

FATIGUE TESTS.

The experiments to determine the results of intermittent or long continued pressure on sandstone and limestone, although not altogether satisfactory, are instructive in showing that stone as a rule, weakens under these conditions. The greatest difficulty in obtaining satisfactory results comes from being unable to tell within a range of from one to five thousand pounds the crushing strength of the samples to be tested. For example, seven tests on limestone from one of the quarries gave results ranging from 11,163 pounds per square inch to 20,261 pounds per square inch. The pieces giving these results were cut from the same block, yet there is a difference in strength of 9,000 pounds per square inch. This, of course, is an extreme case, but shows the wide variance in results obtained in testing pieces of stone from the same block. The average of the seven tests referred to above was 14,376 pounds per square inch. In performing the fatigue tests, it is thought that it is only fair to take the average crushing strength, which in this case, is almost 6,000 pounds per square inch lower than the maximum crushing strength. Any piece which might be used in these tests might have a strength either above or below the average. If an attempt were made to subject the stone to a pressure under the average it might fail before all this load was applied. If this load were sustained upon the first application, but should break after three or four applications of the same load, one would know that the stone was weakened by repeating the load, but to what extent there is no method of knowing.

The average crushing strength obtained for two-inch cubes of Carthage limestone is 59,645 pounds. The first piece subjected to intermittent stresses broke after a load above and below this was applied three times. In each case the load was applied for thirty seconds. The first load was 61,500 pounds, the second 60,000 pounds, and the third 58,000 pounds. In the case of the second piece tested, the initial load applied was 52,000 pounds. After eight applications of thirty seconds each, the piece broke with an explosion at 49,800 pounds. The third piece was subjected to eleven applications of loads varying from 49,200 to 50,700 pounds. The fifth application of the load cracked one corner of the piece. The tenth application of the load, 50,000 pounds, caused the piece to crack. The eleventh application of a load of 30,000 pounds broke the cube ex-



LIMESTONE.

Pyramids resulting from crushing two-inch cubes of Limestone.

plosively. The fourth piece was subjected seventy-three times to loads varying from 47,000 pounds to 51,900 pounds without any effect whatever. At this point, the load was increased to 65,000 pounds at which a corner was cracked off from the piece. Loads of 60,000 pounds, 57,500 pounds, and 61,000 pounds were then applied. Upon application of the last load, the sample broke.

Samples of the cotton rock from Frech's quarry at DeSoto were tested in the same manner as the Carthage limestone with the following results: The average crushing strength of two-inch cubes of this stone is 53,450 pounds. In the case of the first sample tested a load of 47,100 pounds caused a corner to flake off. The tenth application was 43,000 pounds, at which the sample broke. At the third application of 46,600 pounds, a corner broke off, and at the eighth application of 47,200 pounds, the piece cracked on one side. In the case of the second piece tested, the initial load of 45,000 pounds caused a corner to be broken off. The eighth load of 44,100 pounds broke the piece. In the case of the third specimen, a load of from 41,800 to 44,700 pounds was applied without any effect except the chipping off of the corners. In the case of the fourth sample the initial load of 58,500 pounds broke off one of the corners. At the twentieth application, which was 53,700 pounds, the sample failed.

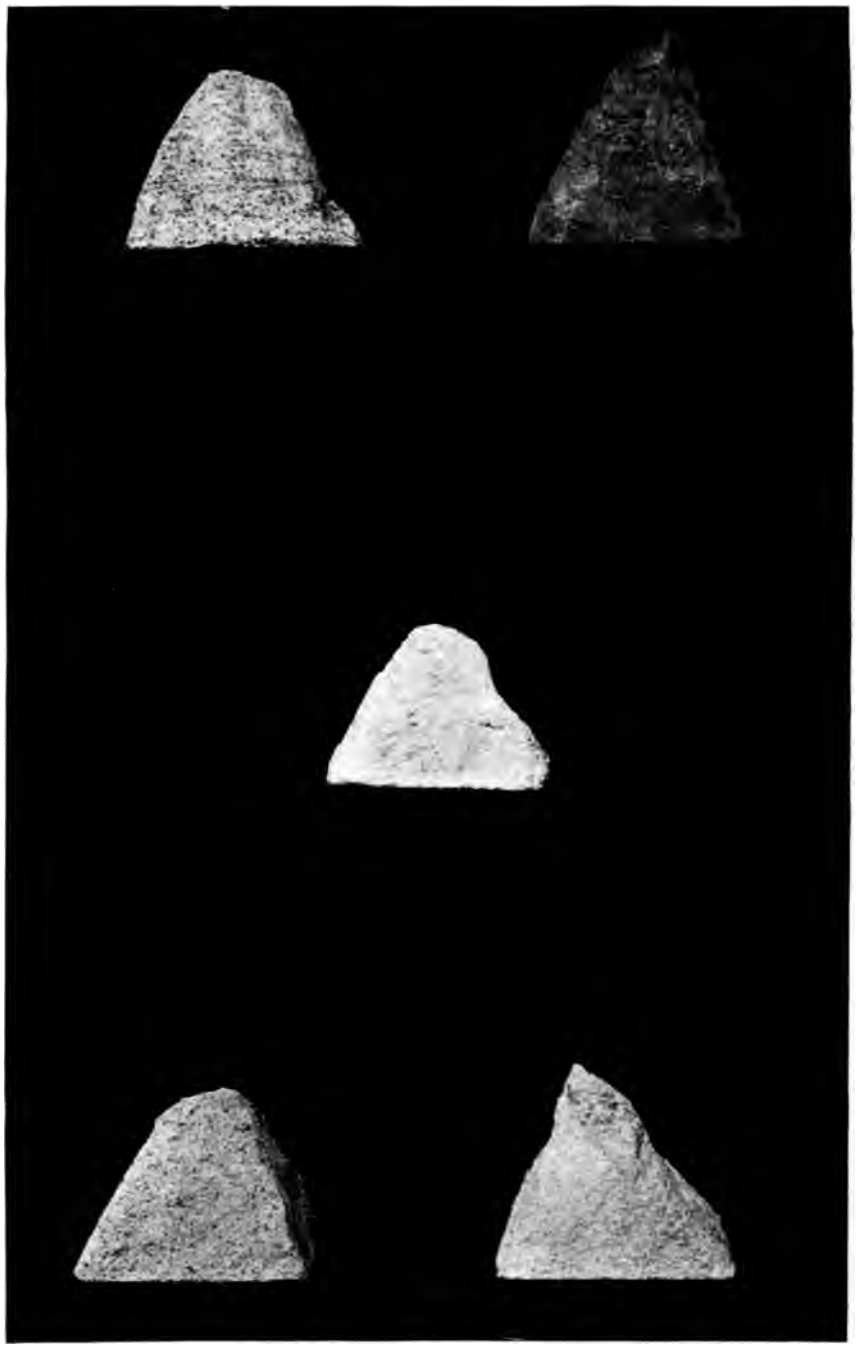
Limestone from the quarry of the Hannibal Lime Co. has an average crushing strength of 9,286 pounds per square inch. Cubes having bearing faces of approximately four square inches have an average crushing strength of 37,505 pounds. The first sample tested was subjected to a load of 35,000 pounds, as a result of which one corner was broken. The load was applied ten times, the last being 33,800 pounds. The sample broke suddenly developing a very good lower pyramid. The second sample was subjected to thirty-five applications, all except the thirteenth being close to 34,000 pounds. The sample broke quietly. The third sample was subjected to an initial load of 33,000 pounds, as a result of which three of the corners flaked off. Altogether a load of from 33,000 to 31,500 pounds was applied forty-six times. The last, or forty-seventh load, at which the sample broke, was 22,400 pounds. The difference between this and the average crushing strength is a little over 15,000 pounds.

The average crushing strength of the stone from the white ledge of the Stolle Stone Co.'s quarry is 13,032 pounds per square inch. The average crushing strength of cubes having faces of approximately four square inches is 53,837 pounds. The first sample was subjected to an initial load of 40,000 pounds, as a result of which one of the corners cracked. With the application of the eighth load, which was 39,000 pounds, the sample

broke. The second sample was subjected to an initial load of 45,000 pounds. This load was repeated five times without injuring the stone. The load was then raised to 50,900 pounds and the sample left in the machine fourteen hours. The load was then raised to 52,000 pounds and left until noon. The specimen showed no evidence of failure. The third specimen was subjected to an initial load of 75,000 pounds; the seventh load applied was 80,000 pounds; the eighth load 79,000 pounds. At this stage, one of the corners cracked off. The load was then gradually decreased with each application until it broke at 70,000 pounds which was the forty-third application. It will be observed that at one stage of the test, the sample sustained a load of 80,000 pounds which is 10,000 pounds higher than the load which caused it to fail. It is evident that in this particular instance at least, the intermittent stress resulted in weakening the stone.

The sandstone from the Morris quarry at Montrose has an average crushing strength of 5,371 pounds per square inch on bed. Cubes which have faces of approximately four square inches have an average crushing strength of 15,060 pounds. The first sample was subjected to an initial load of 14,000 pounds. For thirteen consecutive applications, the load was varied from 13,800 pounds to 14,600 pounds. With the second application, one of the corners cracked slightly. This also happened with the fifth application. With the fourteenth application, in which the load was 10,870 pounds, the stone quietly failed. The second sample was subjected to an initial load of 13,000 pounds. The second load of 14,000 pounds cracked one corner. The following eight applications of loads ranging from 12,600 pounds to 13,200 pounds showed no effect. Upon application of the eleventh load of 11,000 pounds, the stone broke quietly. The third sample was subjected twelve times to a load of 12,500 pounds and fifty-one times to a load ranging from 13,200 pounds to 16,000 pounds without injury to the sample. Later this cube was broken at 21,000 pounds. It is rather difficult to account for the high crushing strength of this sample, which is evidently an exception to the rule.

The asphaltic sandstone from the quarry of the Liberal Stone and Coal Co. has an average crushing strength of 9,002 pounds per square inch on bed. The average crushing strength of three cubes, the bearing surfaces of which are approximately four square inches, is 33,096 pounds. The first sample broke at 29,000 pounds, not reaching the average. The second sample broke at 28,000 pounds, also being below the average. The third sample stood up under a load of 24,000 pounds, but was slightly cracked. After twelve applications of a load of 22,000 pounds this stone broke.



SANDSTONE.

Pyramides resulting from crushing two-inch cubes of Sandstone.

In most of the above tests, the stone flaked or cracked after a load below the average crushing strength had been applied. With very few exceptions, the pieces of stone broke under a load considerably under that which was initially applied to the stone. However, these tests are so few in number that it is difficult for one to formulate any law which will guide him in estimating the probable loss in strength due to intermittent pressure.

Eighteen or twenty pieces of sandstone and limestone were tested to determine, if possible, *the effect of long continued pressure* below the ultimate crushing strength of the stone.

As determined by previous tests, the average crushing strength of one of the sandstones was about 9,000 pounds per square inch. It was, therefore, determined to try a load of 8,000 pounds. However, each of the specimens broke before this load was reached. In the case of the second sandstone tested, it was determined to apply a load of less than the ultimate crushing strength. Fourteen thousand pounds was applied to the two-inch cube for nine hours. It did not break and the load was increased to 21,700 pounds, at which the sample broke. The second sample of this stone broke when a load of 13,800 pounds was applied.

Samples of the Hannibal limestone were placed in the machine under 35,000 pounds pressure. The three samples were subjected to this pressure two hours, six hours, and sixteen hours, respectively. In the case of the first the pressure was raised to 46,000 pounds before the piece broke. In the other two cases the load was increased to 48,000 pounds before the samples failed.

A two-inch cube of Carthage limestone was subjected to a pressure of 45,000 pounds for eighty-eight hours without breaking. The load was then increased to 70,000 pounds, at which the specimen broke. Another sample was subjected to a load of 50,000 pounds for twenty-two hours and finally broke when the pressure was increased to 58,000 pound.

A two-inch cube of cotton rock was subjected to a pressure of 45,000 pounds for nineteen hours without breaking. The load was then increased to 56,000 pounds, at which the sample failed. Another sample was subjected to a pressure of 50,000 pounds, breaking in ten minutes from the time the load was applied. A load of 47,000 pounds was applied to a third sample which broke at the end of five and a half hours, without increasing the pressure. A sample of St. Louis limestone was subjected to a pressure of 60,000 pounds for twenty-one hours without breaking. The load was then increased to 70,000 pounds and held one and one-fourth hours, after which it broke. Two other samples of

this limestone broke at 51,000 and 58,000 pounds respectively before the initial load was reached.

These tests are too few to draw conclusions from. They are interesting, however, in showing that, in some cases at least, a stone will fail after a load below the ultimate crushing strength has been applied for a few hours. This is all that can be said relative to the results of these tests.

TRANSVERSE STRENGTH.

Next, or perhaps of greater importance than the crushing strength, is the transverse or cross breaking strength. This is measured in terms of the modulus of rupture and the determinations are made after the manner described in Chapter III. A knowledge of the transverse strength is valuable in estimating the required thickness of stone when supported only at the ends, as in the case of lintels, sidewalks, cover-stones for culverts, etc. The only way to determine the capacity of different stones to support loads when in these positions, is to determine experimentally the modulus of rupture.

Limestone.—Seventy-one pieces from sixteen different limestone quarries were used in making the determinations given in Table IV. in the latter part of this chapter. From three to five pieces were tested from each quarry and the results averaged. The lowest modulus of rupture was 851.3 pounds per square inch, while the highest was 3,311.6 pounds per square inch. All of the pieces had a cross section of one inch and a span of six inches.

The stone from ten of the quarries gave a modulus of rupture of over 2,000 pounds per square inch. That from the Kesterson quarry of Jackson gave the highest test, 3,311.6 pounds per square inch. The tests were all remarkably high and uniform and give very conclusive proof that the stone from all important limestone quarries in this State can be used with safety in positions requiring a moderately high transverse strength.

Sandstone.—Twenty-four tests were made on the sandstone from five different quarries. The results of these tests are much lower than for the limestones. The highest average test was obtained on stone from the quarry of the Carroll County Sandstone Co. at Miami. This stone has a modulus of rupture of 1,321.76 pounds per square inch. The lowest test was obtained on samples of yellowish brown sandstone from the quarry of the Liberal Stone and Coal Co. at Liberal. This stone has an average modulus of rupture of 418.61 pounds per square inch. Asphaltic sandstone from the same horizon gave an average modulus of rupture

of 763.6 pounds per square inch. The average modulus of rupture of the sandstone from Pickel Bros. quarry at Warrensburg was determined to be 777.97 pounds per square inch.

Some of the sandstone has a modulus of rupture which is somewhat lower than is ordinarily required for stone used as caps in heavy buildings. It is thought, however, that most of the stone tested might be used without danger in buildings of ordinary size. A stone having a low modulus of rupture must be thicker than one in which the modulus of rupture is high in order to have the same degree of safety. The necessity for using a stone having a high modulus of rupture is sometimes avoided by arching doors and windows instead of using caps.

TENSILE STRENGTH.

In Table V. will be found the results of a series of tests on limestone and sandstone made to determine their tensile strength. In former reports on Building Stones and among the records of tests of materials, I have been unable to find any determinations of the tensile strength of stone. Nevertheless, it has been thought that a series of tests made in the manner described in Chapter III., would not only be of interest to the scientific public, but also of value to architects and builders. The pieces used in making the tests were very carefully prepared and it is thought that the results are as accurate as it is possible to obtain under the conditions. The tensile strength is measured in pounds per square inch and in the table both the maximum and the average tensile strength are recorded.

Limestone.—Sixty-three pieces from sixteen different limestone quarries were used in making this series of tests. A 1,000 pound machine was used in breaking the briquettes. The samples from the quarry of the Hughes Stone Co., at Noel, could not be broken in this machine. The stone from the quarry of the Stolle Stone Co. at St. Louis, the Fullerton quarry at Princeton, and the Kesterson quarry at Jackson tested between 1,000 and 1,100 pounds per square inch. The lowest test was 220 pounds per square inch on pieces of pitted dolomite. The pieces giving this low test were filled with small cavities. Pieces of the same kind of rock from another quarry gave an average tensile strength of 727 pounds per square inch.

Sandstone.—Fifteen pieces from three different sandstone quarries were tested with the results given in Table V. The asphaltic sandstone from the quarry of the Liberal Stone and Coal Co. gave the highest test, which was 344½ pounds per square inch. The yellowish colored sandstone from the same area gave the lowest result, which was 202⅔ pounds per square inch.

By referring to the diagram on a following page, it will be seen that the tensile strength tests fluctuated more or less uniformly with the transverse strength tests. On an average, the tensile strength is about one half that obtained in the transverse strength tests.

SPECIFIC GRAVITY.

The specific gravity determinations made in the preparation of this report are what is known as the specific gravity proper. They represent the specific gravity of the mineral particles composing the rock and have no relation whatever to the porosity. A high specific gravity will naturally increase the weight of a rock per cubic foot, while an increase in the percentage of pore space will decrease the weight proportionately. In order to compute the weight per cubic foot of stone by using the specific gravity proper, one should also know the porosity. The method employed in making these tests is described in Chapter III.

Limestone.—Fifty-one two-inch cubes of limestone from twenty-two quarries were used in making the specific gravity determinations. These determinations were made according to the method outlined in Chapter III. of this report. There is quite a range in the specific gravity of limestone, depending chiefly upon the quantity of magnesium present. The highest specific gravity was obtained for samples of pitted dolomite obtained from the Kieselbach quarry at Jefferson City and from the White quarry at Rolla. The stone from these quarries has an average specific gravity of 2.80. The lowest specific gravity was obtained for stone from the Breckenridge Stone Co.'s quarry at Breckenridge. This stone has an average specific gravity of 2.454. The stone next lowest in specific gravity is that from the upper ledge of the Fullerton quarry at Princeton, which has a specific gravity 2.585. The average specific gravity of the stone from quarries in the Burlington limestone ranges from 2.656 to 2.716. The average specific gravity of all specimens of dolomite from quarries in the Cambro-Ordovician formations ranges from 2.776 to 2.80.

Sandstone.—Twelve two-inch cubes of sandstone from five quarries were tested to determine their specific gravity. The lowest was that of the asphaltic sandstone from the quarry of the Liberal Stone and Coal Co., at Liberal, which tested 2.445. The highest specific gravity was obtained for the sandstone from the Morris quarry at Montrose and the quarry of yellowish brown sandstone of the Liberal Stone and Coal Co. at Liberal.

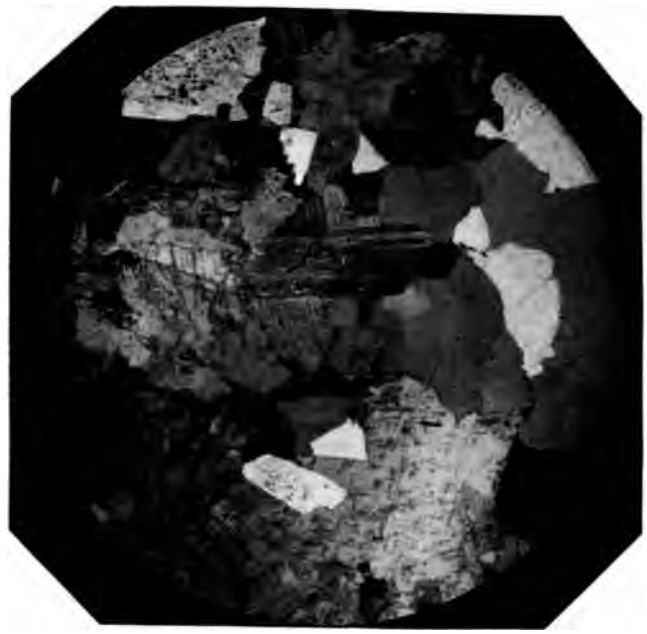


FIG. 1.

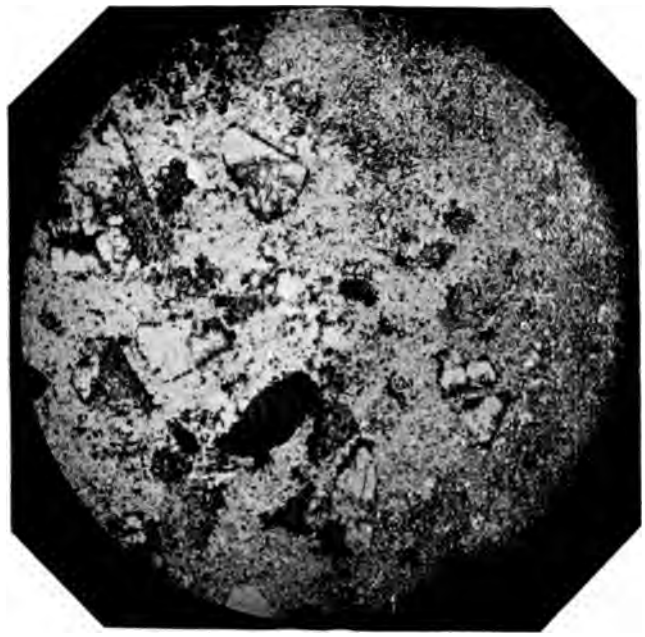


FIG. 2.

MICROPHOTOGRAPHS.

Fig. 1. Granite, Graniteville, Mo. (X12).
Fig. 2. Rhyolite, Piedmont, Mo. (X12).

POROSITY AND RATIO OF ABSORPTION.

In Chapter III. there is a full discussion of porosity and ratio of absorption. The difference between the two is pointed out and methods of determining each are fully considered. It is sufficient at this place to say that the porosity is considered to be the percentage of actual pore space in the rock, while ratio of absorption is simply the percentage which the weight of the absorbed water bears to the average weight of the dry sample. Both determinations have been made for the samples of stone tested in the preparation of this report. They will be found in adjacent columns in Table VI. at the close of this chapter. By reference to this table, it will be observed that there is no definite relation between the porosity and ratio of absorption, although it may be said that the porosity is about two and a half times the ratio of absorption. The difference in the ratio between the two depends chiefly upon variations in the specific gravity of the different rocks.

Very few of the samples tested have a porosity of more than 10 per cent. and only three have a ratio of absortpion exceeding this percentage.

Limestone.—The porosity and ratio of absorption were determined for fifty-one samples of limestone and dolomite from twenty-two quarries. The highest average porosity was obtained for limestone from Rymer Bros. quarry at Sedalia, and the lowest average porosity was obtained for limestone from Kesterson's quarry at Jackson. The highest porosity was 13.38 per cent., while the lowest was 0.32 per cent. The same samples showed the highest and lowest ratio of absorption. The highest was 5.62 per cent. and the lowest 0.12 per cent.

Sandstone.—Twelve samples of sandstone from five quarries were tested to determine their porosity and ratio of absorption. The highest average porosity was obtained for samples of sandstone from the Morris quarry at Montrose. The lowest average porosity was obtained for samples of asphaltic sandstone from the quarry of the Liberal Stone and Coal Co., of Liberal. The highest porosity is 23.77 per cent and the lowest 7.01 per cent. The same samples show the highest and lowest average ratio of absorption. The highest ratio of absorption is 11.37 per cent. and the lowest 3.05 per cent.

It has been the practice to question the durability of a stone which absorbs more than 10 per cent. of its weight of water. It has been pointed out in Chapter III., that the danger from freezing and thawing of water contained in the pore spaces of a rock does not depend so much

upon the percentage of pore space as it does upon the size of the pores. A rock having a porosity of 20 per cent. or 25 per cent. may never be in danger of freezing, owing to the rapidity with which it gives off the water which is contained in the pores. A stone having very large pores may frequently be laid in a wall during the cold winter months without injury, while marble or limestone having a low porosity and small pore spaces may be in constant danger if used immediately after being quarried. The chart, Plate LIX., in which are plotted the porosities and losses in crushing strength due to the freezing test, shows clearly that there is no relation between the two.

WEIGHT PER CUBIC FOOT.

Table VI. gives the weight per cubic foot of the stone from the more important limestone and sandstone quarries in this State. It is not practicable to attempt to give the weight of the stone as it comes from the quarry on account of the variations in the amount of water which it contains. The results in this table are computed on a basis of the specific gravity and porosity of the stone and they apply only to stone which is perfectly dry. The heaviest stone is that obtained from Kesterson's quarry at Jackson, the weight being 168.5 pounds per cubic foot. The lightest stone is that from the Morris quarry at Montrose. This is a sandstone weighing 128.7 pounds per cubic foot.

Limestone.—A cubic foot of limestone ought not to weigh more than a cubic foot of solid, crystallized calcium carbonate or calcite. The maximum specific gravity of pure calcite is 2.723 (Dana), the weight then of a cubic foot of solid calcite would be 2.723x62.5 pounds (the weight of a cubic foot of water) which is 170.19 pounds. In the same manner the weight of a cubic foot of solid dolomite would be 2.9x62.5 pounds, which is 181.25 pounds. However, a stone contains a greater or lesser per cent. of pore space which reduces the weight of the stone below the maximum theoretical determination.

The weight per cubic foot of the limestones and dolomites tested in the preparation of this report ranges from 141.2 to 168.4. These weights may be a trifle low, but are as nearly accurate as it is possible to obtain for the pieces tested. The weight of the Carthage limestone was determined to be 167 pounds per cubic foot. That from Springfield weighs 168.1 pounds per cubic foot, while the stone from Joplin and Pierce City weighs 165 pounds per cubic foot.

The strength and durability of a stone do not depend upon its weight, although this may give one an idea of the porosity of the stone, provided the mineralogical composition is known.

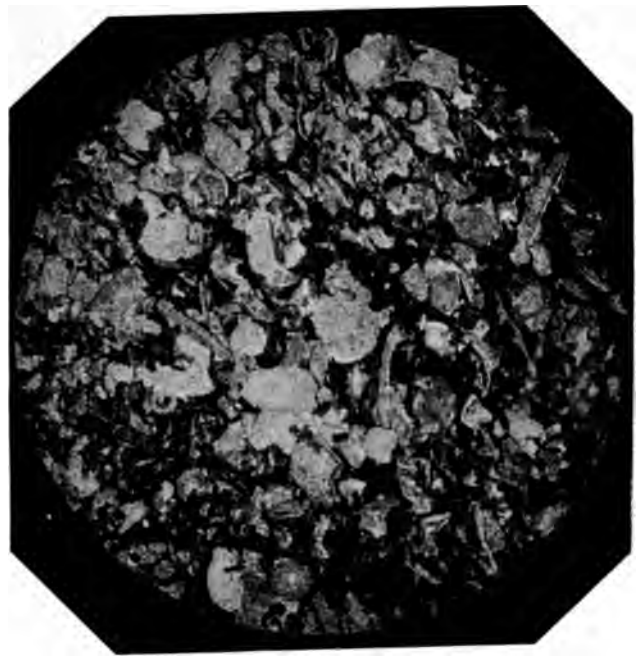


FIG. 1.

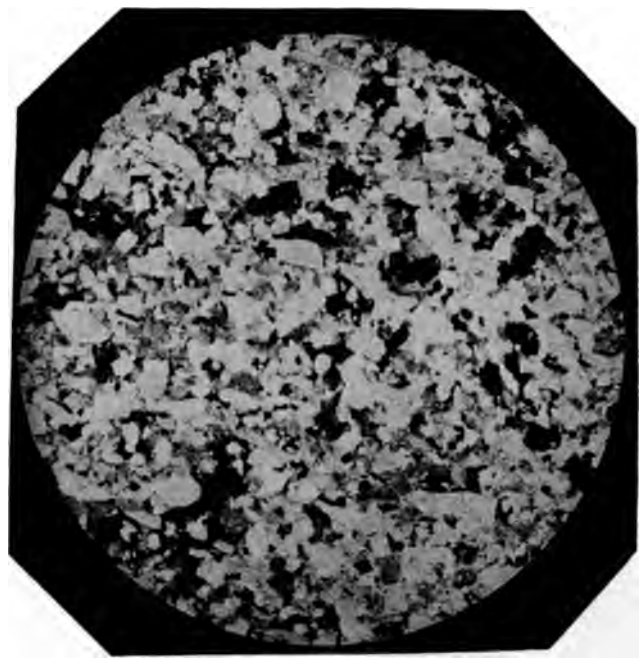


FIG. 2.

MICROPHOTOGRAPHS.

Fig. 1. Carthage Limestone (X12).
Fig. 2. Warrensburg Sandstone (X15).

Sandstone.—In its pure form, sandstone consists of grains of quartz. If there were no pores and the stone was simply crystallized quartz, a cubic foot should weigh about 165.88 pounds. The maximum weight obtained for the specimens tested in the preparation of this report was 142.1 pounds which is the weight of a cubic foot of asphaltic sandstone from the Liberal Stone and Coal Co.'s quarry, at Liberal. The lightest stone is that from the Morris quarry at Montrose. The weight of this stone was computed to be 128.7 pounds per cubic foot.

The relation which the weight bears to the porosity, ratio of absorption and specific gravity, is shown in the diagram which follows Table VI., at the close of this chapter.

FREEZING AND THAWING TESTS.

The results of alternate freezing and thawing are manifested in three ways. First, by the formation of cracks; second, by the removal of small particles or grains from the surface, resulting in a loss in weight; and third, by a lowering of the strength of the stone. Owing to the care which is usually taken in selecting and preparing samples to be tested, the first case is seldom observed. It is thought that the loss in weight does not represent the injury resulting from freezing and thawing of the included water. This can be better estimated by comparing the results of crushing strength tests on frozen and fresh samples.

Formation of Cracks.—Some of the samples tested cracked as a result of the freezing test. One set of cubes from the quarry of Butters and Son opened up along the bedding planes. Another set from this same quarry gave no evidence of injury. Some of the pitted dolomite cubes had their corners broken off. The samples of Carthage limestone, containing suture joints, gave no sign of injury.

Loss in Weight.—Occasionally small particles are removed from the surface as a result of the pressure of freezing water. Hammer dressed or sawed pieces of sandstone usually have grains on the exterior which have been partly loosened through the process of dressing. The cracks which are thus formed will hold water which, when frozen, exerts a pressure sufficient to remove the loose particles.

More grains are naturally removed from the sandstone than from the limestones or igneous rocks. It is therefore evident that the loss in weight will be proportionately greater in the sandstones. The loss in weight depends chiefly upon the manner in which the samples have been dressed. It does not in any way indicate the extent to which the stone has been injured.

Previous to the publication of the report on the "Building and Ornamental Stones of Wisconsin," this fact was evidently not recognized. The first determinations of the loss in crushing strength due to alternate freezing and thawing, of which I have any knowledge, were published in that report.

The loss in weight as the result of alternate freezing and thawing was determined for all of the samples tested in the preparation of this report. These results are given in Table VII and the manner in which the tests were performed is described in Chapter III. The table shows that the limestones and dolomites lost from .006 per cent. to .909 per cent. in weight after being subjected to the freezing test. The sandstones lost from .111 to .591 per cent. in weight. The losses in weight are almost insignificant and are valuable mainly in showing that the grains on the exterior of the loosely compacted sandstones are more generally loosened in cutting the sample than are the individuals which compose the limestones.

That there is no relation between the loss in weight and loss in strength due to the freezing test is shown by the diagram following Table VII.

Loss in Crushing Strength.—All of the specimens subjected to the freezing test were broken in a testing machine to determine their crushing strength. It is very plain that a stone which is saturated with water and then frozen repeatedly for a score or more of times will be weakened to such an extent that it will not be able to withstand the pressure of a fresh cube. The weakening of the stone may not show on the exterior, but will develop when subjected to compressive stresses in the testing machine. Table VII. gives the results of the crushing strength tests on the samples subjected to the freezing test, while Table VIII. gives a comparison between the strength of the fresh and frozen samples. The comparative strength of the fresh and frozen samples is also shown in the diagram which accompanies this table. Out of thirty-four sets of samples tested, only eleven gave an average crushing strength higher than that of the fresh samples. It appears from the diagram, which includes only the limestones, that the samples having a high crushing strength were more uniformly affected by alternate freezing and thawing than those having a low crushing strength.

In Table VIII., the results which are given, show an increase in the strength of the frozen over the fresh samples. The results are averages of from two to six tests. There is quite a wide range in the results, but this must be expected in the case of materials which are no more uniform than stone. It is somewhat difficult to account for an increase of 2,000

pounds in the average crushing strength of the frozen stone over the fresh, as in the case of the specimens from Butters and Son's quarry. It is also difficult to understand how the crushing strength of the frozen samples of sandstone from Miami should be greater than that of the fresh samples, except that porosity has no relation to the results of alternate freezing and thawing.

THE EFFECT OF SULPHUROUS ACID GAS.

Samples of limestone from fourteen quarries and sandstone from five quarries were tested to determine the effect of sulphurous acid gas in a moist temperature. The samples were placed under a bell jar and subjected to very strong SO_2 in a very damp atmosphere for fifty days. The pieces of stone were placed upon asbestos which in time became wet. In the case of at least two samples, this seemed to cause a very vigorous action.

When taken from the bell jar, the samples had a dark color. The Burlington limestone appeared to be little, if any, affected by this treatment. The sandstones were evidently affected in some unknown way as shown by the increase in weight.

The dolomites were seriously affected, becoming yellow, increasing in size as much as $33\frac{1}{3}$ per cent., and finally cracking and crumbling into powder. This change seems to have been due to the alteration of the dolomite into magnesium sulphate. The powder was digested with distilled water and found to contain a large per cent. of soluble magnesium sulphate. All the so-called cotton rock, pitted dolomite and the magnesium limestone from Bowling Green show this peculiar form of deterioration when treated with sulphurous acid gas in a moist atmosphere.

Some of the specimens crumbled so completely that it was impossible to weigh them after treatment. Others that could be handled showed an increase in weight. The sample from Frech's quarry at DeSoto increased almost four per cent. in weight. Had the specimens been allowed to soak in water the magnesium sulphate would probably have been, in a large measure, taken into solution. In this case the samples would have weighed less rather than more than they did originally.

TABLE NO. IV.

TRANSVERSE STRENGTH.

LIMESTONE.

Name of quarry.	Location.	No. of pieces tested.	Length of span in inches.	Av. breadth in inches.	Average depth in inches.	Maximum modulus of rupture.	Average modulus of rupture.	Remarks.
Butters & Son	Bowling Green	4	6	1.040	1.060	2395.2	2,023.32	
Breckenridge Stone Co	Breckenridge	3	6	1.012	1.008	1390.4	1,341.46	
Carthage Marble and White Lime Co	Carthage	5	6	1.040	1.030	2916.0	2,285.5	
Frech	DeSoto	4	6	1.013	1.010	2893.9	2,219.55	
Hannibal Lime Co	Hannibal	4	6	1.009	1.019	1824.9	1,745.30	
Kesterson	Jackson	4	6	1.026	1.023	4418.8	3,311.60	
Kieselbach	Jefferson City	4	6	1.021	1.001	2563.5	2,458.53	Cotton rock
Mueller & Geisler	" "	4	6	1.016	1.019	3098.8	2,949.22	Cotton rock
" "	" "	4	6	1.018	1.019	1698.0	1,228.80	Pitted dolomite
Shoal Creek	Joplin	4	6	1.012	1.002	.....	1,350.00	
Phenix Stone and Lime Co	Phenix	4	6	1.011	1.015	1730.0	1,684.70	
Peirce City Building Stone Co	Peirce City	4	6	1.064	1.053	2337.0	2,079 46	
Fullerton	Princeton	4	6	1 015	1.016	3342.3	2,685.02	Lower ledge.
"	"	3	6	1.012	1.017	1322.15	1,175.61	Upper ledge.
White	Rolla	4	6	1.011	1.009	1211.0	851.30	Pitted dolomite
Rymer Bros	Sedalia	4	6	1.012	1.016	2185.3	2,118.07	
Knapp	Sheffield	4	6	1.005	1.015	1920.3	1,644.51	Bethany Falls limestone
Stolle Stone Co	St. Louis	4	6	1.015	1.010	2822.4	2,727.40	Stockton ledge

SANDSTONE.

Curless	Liberal	4	6	1.004	1.011	753.1	708.90	
Liberal Stone and Coal Co	"	4	6	1.011	1.015	817.9	783.60	Asphaltic sandstone
" " "	"	4	6	1.003	1.015	453.9	418.61	Yellowish brown sandstone.
Carroll County Sandstone Co	Miami	4	6	1.010	1.019	1414.0	1,321.76	
Morris	Montrose	4	6	1.013	1.001	644.5	567.70	
Pickel Bros	Warrensburg	4	6	1.011	1.035	895.4	777.97	

TABLE NO. V.

TENSILE STRENGTH.

LIMESTONE.

Name of quarry.	Location of quarry.	No. of pieces tested.	Maximum tensile strength in lbs per sq. inch.	Average tensile strength in lbs per sq. inch.	Remarks.
Butters & Son	Bowling Green	3	626	598	One of the pieces was weathered
Breckenridge Stone Co	Breckenridge	3	584	565	One piece was imperfect
Frech	DeSoto	4	1036	983	
Hannibal Lime Co	Hannibal	4	816	744 1/3	
Kesterson	Jackson	3	1154	1,076 1/3	One piece could not be broken in the machine used
Kieselbach	Jefferson City	4	926	862 2/3	Cotton rock
"	" "	4	824	727	Pitted dolomite
Mueller & Geisler	" "	4	1054	970 2/3	Cotton rock
" "	" "	4	752	498 1/3	Three pieces contained many cavities
Lyle Rock Co	Kansas City	3	986	971	
Schlief	Koeltztown	2	488	364	Pitted dolomite
Hughes Stone Co	Noel	3			Could not break the pieces in 1,000 lb machine
Phenix Stone and Lime Co	Phenix	4	1034	883 1/3	Fine grained
" " "	"	4	622	446 1/3	Coarse grained
Fullerton	Princeton	2	1050	1025	Lower ledge
"	"	2	740	730	Upper ledge
White	Rolla	1	220	220	Very poor pieces of pitted dolomite
Rymer Bros	Sedalia	2	840	792	
Knapp	Sheffield	4	972	713 1/3	One piece broke along an open bedding plane. Another along a stylolite
Stolle Stone Co	St. Louis	3	1135	1052 1/3	

SANDSTONE.

Curless	Liberal	4	314	306 1/3	Yellowish colored
Liberal Stone and Coal Co	"	3	212	202 2/3	" "
" " "	"	4	352	344 1/3	Asphaltic sandstone
Morris	Montrose	4	272	254 1/3	

TABLE NO. VI.

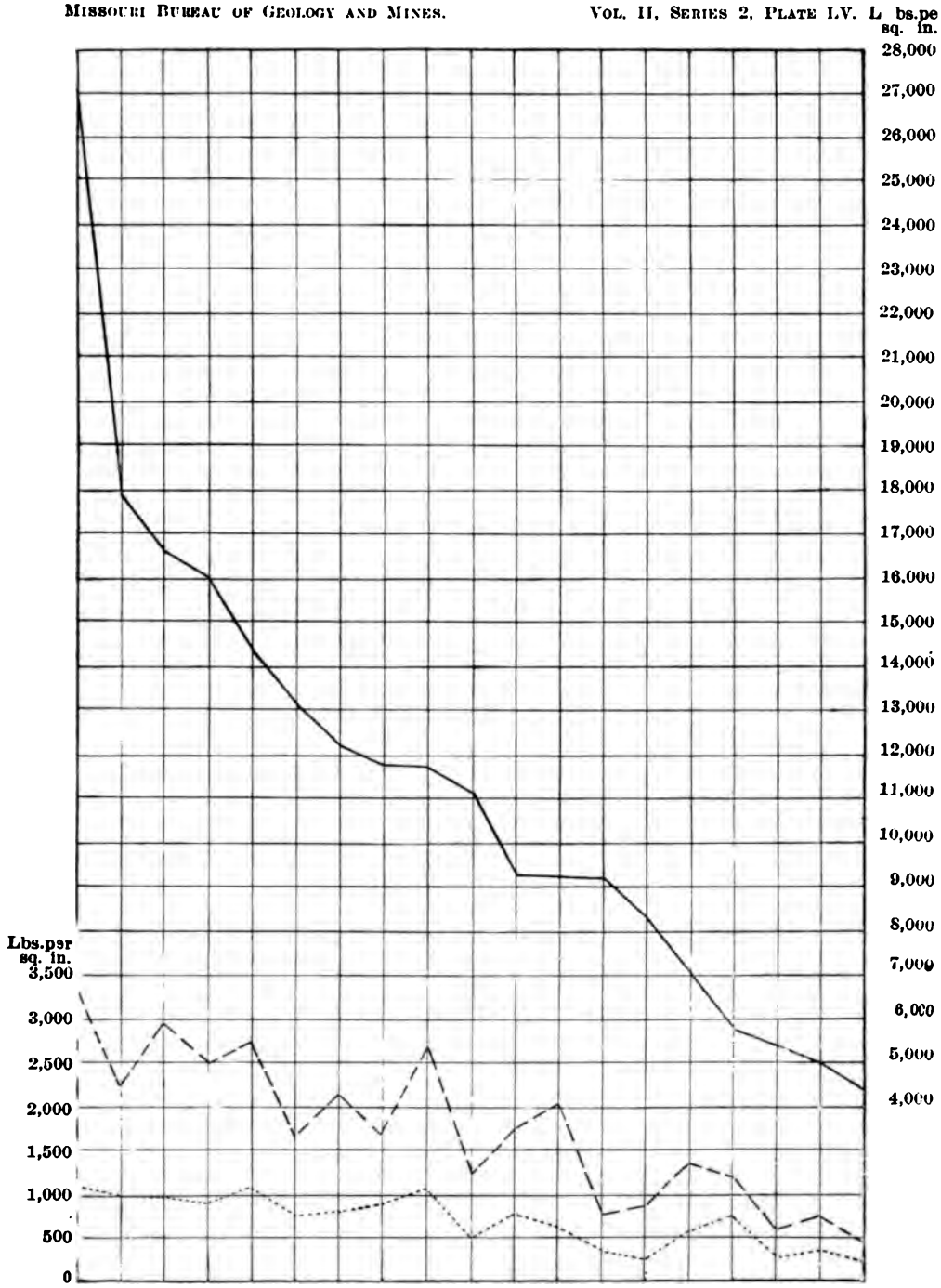
AVERAGE CRUSHING, TRANSVERSE AND TENSILE STRENGTHS ARRANGED FOR COMPARISON.

LIMESTONE.

Name of quarry.	Location of quarry.	Av. crushing strength On bed in lbs per sq. inch.	Av. transverse strength in lbs per sq. inch.	Av. tensile strength in lbs per sq. inch.	Remarks.
Butters & Son	Bowling Green	8,881	2,023.32	598	
Breckenridge Stone Co.	Breckenridge	6,944	1,310.46	565	
Frech	DeSoto	17,834	2,219.55	983	
Hannibal Lime Co.	Hannibal	9,246	1,745.30	744¼	
Kesterson	Jackson	27,183	3,311.60	1,079½	
Kieselbach	Jefferson City	15,965	2,468.53	862½	Cotton rock
Mueller & Geisler	" "	16,672	2,949.22	970¾	Cotton rock
" "	" "	11,140	1,228.80	498½	Pitted dolomite
Phenix Stone and Lime Co.	Phenix	11,748	1,684.70	883½	
Fullerton	Princeton	5,714	1,175.61	730	Upper ledge
"	"	11,696	2,685.02	1,025	Lower ledge
White	Rolla	8,486	851.30	220	
Rymer Bros.	Sedalia	12,995	2,118.07	792	
Knapp	Sheffield	13,140	1,644.51	713¼	
Stolle Stone Co.	St. Louis	17,095	2,727.40	1,052½	

SANDSTONE.

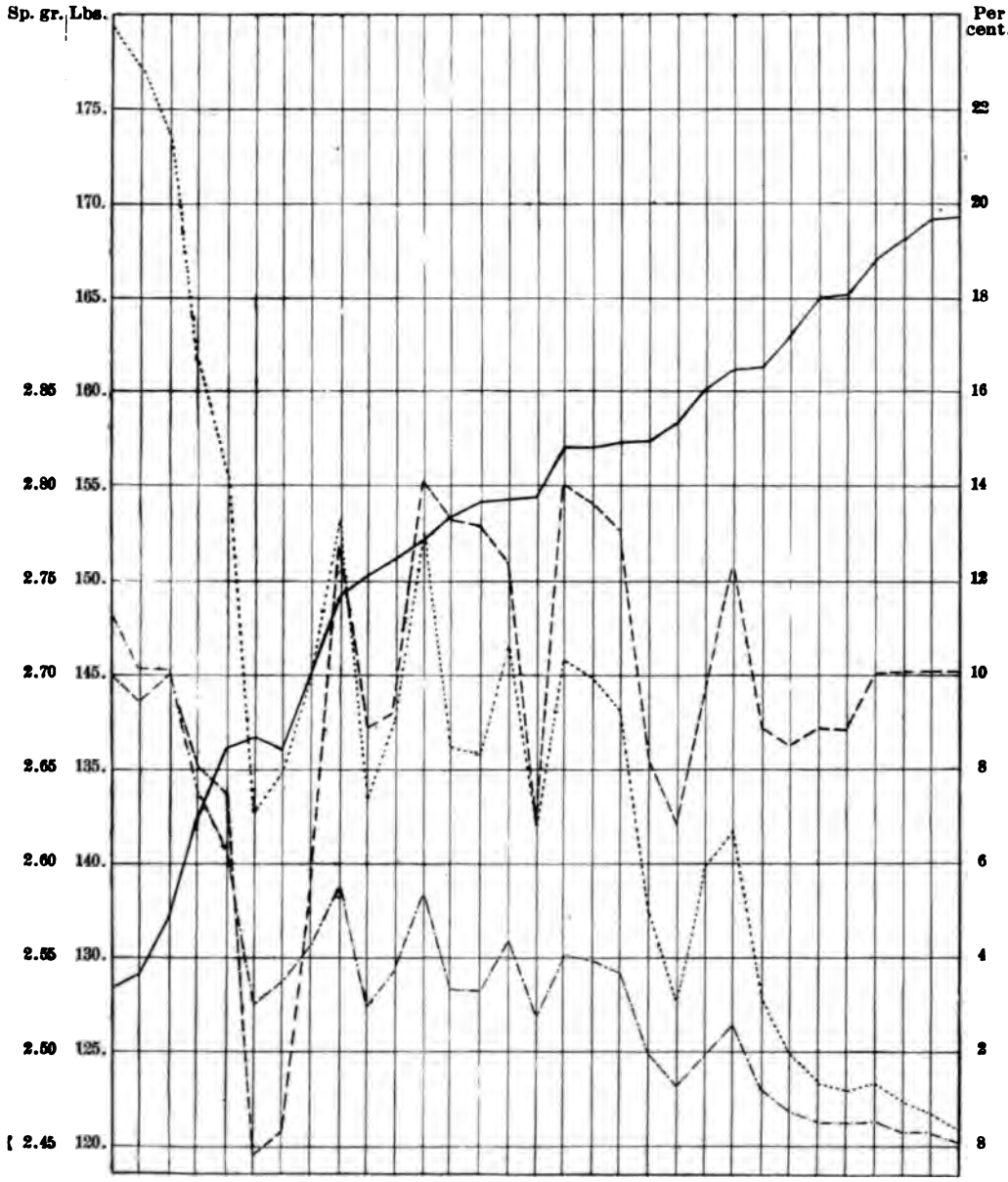
Curless	Liberal	4,942	708.90	306½	
Liberal Stone and Coal Co.	"	4,371	418.61	212¾	Buff sandstone
" " "	"	9,002	763.60	344¼	Asphaltic sandstone
Morris	Montrose	5,371	567.70	254½	



RELATION BETWEEN CRUSHING, TRANSVERSE AND TENSILE STRENGTHS.

——— Crushing strength. — — — Transverse strength. - - - - - Tensile strength.

(Horizontal divisions represent different stones.)



— — Specific Gravity. ——— Weight per cubic foot in lbs.
..... Porosity. — - — - Ratio of Absorption.

(Horizontal divisions represent different stones.)

RELATION BETWEEN THE SPECIFIC GRAVITY, POROSITY, WEIGHT PER CUBIC FOOT AND RATIO OF ABSORPTION

TABLE NO. VII.

SPECIFIC GRAVITY, POROSITY, RATIO OF ABSORPTION AND WEIGHT PER CUBIC FOOT.

LIMESTONE

Name of quarry.	Location.	No. of pieces.	Approximate size of pieces.	Av. specific gravity.	Av. percentage of pore space or porosity.	Av. percentage of the weight of absorbed water to the average dry weight of sample, or ratio of absorption.	Av. weight of the dry stone in lbs. per cubic foot.	Remarks.
Butters & Son	Bowling Green	2	2-in. cubes	2.76	10.62	4.37	154.3	Stone from lower ledge
Breckenridge Stone Co.	Breckenridge	2	"	2.454	7.90	3.49	141.2	
Carthage Marble and White Lime Co	Carthage	4	"	2.708	1.84	0.50	167.0	
Richardson	Columbia	2	"	2.62	3.10	1.23	158.7	
Frech	DeSoto	2	"	2.766	6.717	2.60	161.2	
Hannibal Lime Co.	Hannibal	2	"	2.656	5.03	2.00	157.7	
Kesterson	Jackson	2	"	2.705	0.32	0.12	168.5	
Kieselbach	Jefferson City	2	"	2.776	9.24	3.66	157.5	Cotton rock
"	" "	2	"	2.80	10.32	4.06	157.0	Pitted dolomite
Mueller & Gelsler	" "	2	"	2.783	8.57	3.37	153.8	Cotton rock
" "	" "	2	"	2.779	8.31	3.26	154.1	Pitted dolomite
Shoal Creek	Joplin	1	"	2.671	1.13	0.43	165.1	
Casey	Kahoka	2	"	2.622	6.75	2.76	154.7	
Lyle Rock Co.	Kansas City	2	"	2.98	9.15	3.76	151.3	
Schlief	Koeltztown	2	"	2.79	9.99	3.98	157.0	
Hughes Stone Co.	Noel	2	"	2.711	0.62	0.23	168.4	
Phenix Stone and Lime Co.	Phenix	2	"	2.663	1.94	0.74	163.2	
Peirce City Building Stone Co.	Peirce City	2	"	2.673	1.24	0.47	165.0	
Fullerton	Princeton	2	"	2.69	4.92	1.92	160.1	Lower ledge
"	"	2	"	2.585	10.01	4.30	145.4	Upper ledge
White	Rolla	2	"	2.80	13.00	5.34	152.2	Pitted dolomite
Rymer Bros.	Sedalia	2	"	2.757	13.38	5.62	149.3	
Knapp	Sheffield	2	"	2.673	3.15	1.19	161.8	
Hollman	Springfield	2	"	2.716	0.93	0.34	168.1	
Stolle Stone Co.	St. Louis	2	"	2.672	7.80	2.95	150.3	Stockton ledge

SANDSTONE.

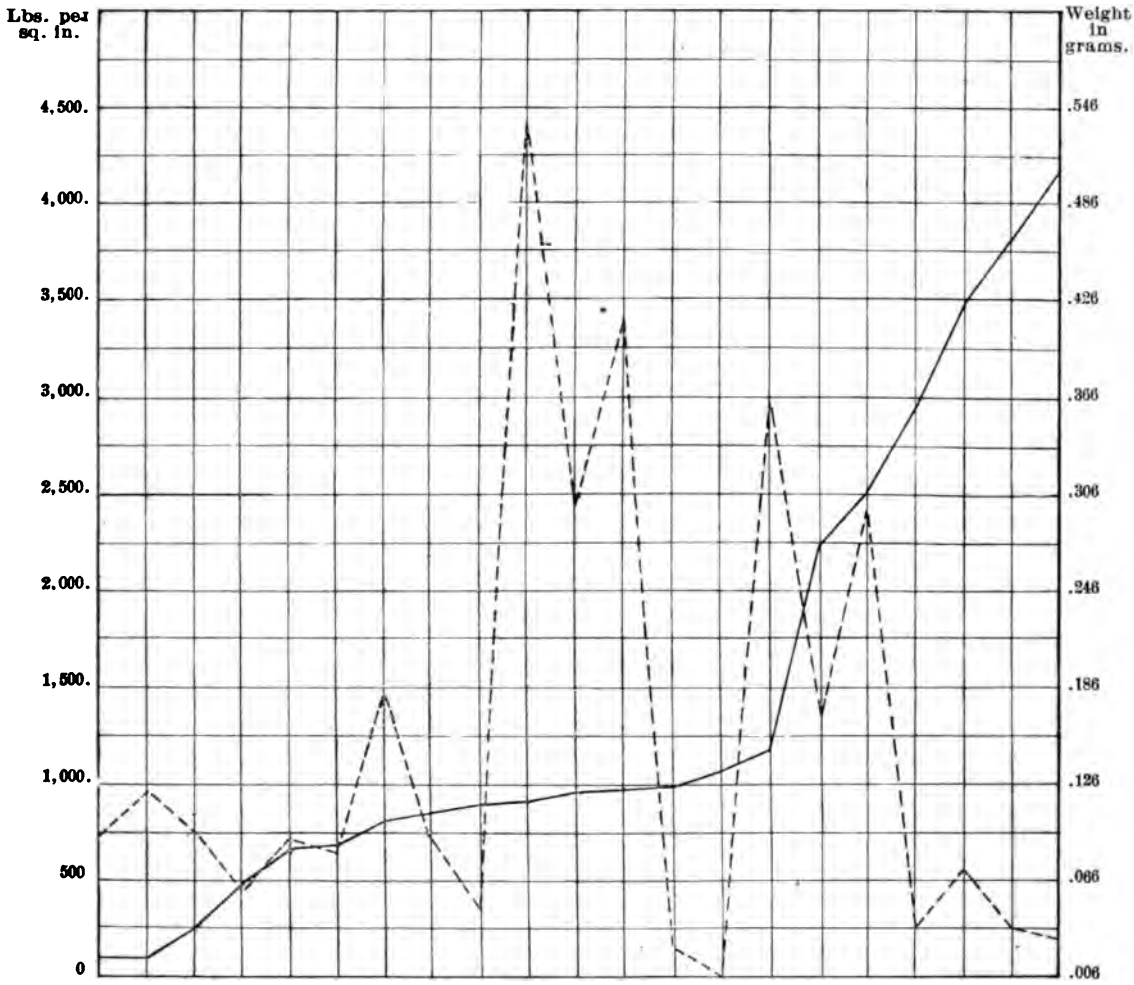
Curless	Liberal	2	2-in. cubes	2.686	22.95	10.23	129.3	
Liberal Stone and Coal Co.	"	2	"	2.445	7.01	3.05	142.1	Asphaltic sandstone
" " "	"	2	"	2.70	21.59	10 20	132.3	Yellowish brown sandstone
Carroll County Sandstone Co.	Miami	2	"	2.637	14.31	6.33	141.3	
Morris	Montrose	2	"	2.70	23.77	11.37	128.7	
Pickel Bros.	Warrensburg	2	"	2.049	16.77	7.64	137.7	

TABLE NO. VIII.

FREEZING AND THAWING TESTS.

LIMESTONE.

Name of quarry.	Location of quarry.	No. of pieces tested.	Average dry weight in grams.	Loss in weight after freezing and thawing 33 times.	Average loss per cent in weight.	Average area of bearing faces.	Position of pieces in testing machine.	Crushing strength in pounds per square inch.	Remarks.
Butters & Son	Bowling Green	4	324.77	0.68	.161	4.07	Bed	11,074	
"	"	4	340.04	Split	along	bedding	planes.		Had well defined bedding planes.
Breckenridge Stone Co.	Breckenridge	4	304.64	0.24	.079	4.11	Bed	8,163	Failed snddenly without noise.
Carthage Marble & White Lime Co.	Carthage	4	366.26	0.17	.047	4.14	"	13,382.7	
" " "	"	3	364.63	0.22	.059	4.14	"	15,865	
" " "	"	4	329.66	0.19	.056	3.88	"	13,921	
Richardson	Columbia	2	340.43	0.30	.088	4.07	"	9,738	
Frech	DeSoto	4	354.66	1.48	.415	4.18	"	16,880	Broke explosively.
Hannibal Lime Co.	Hannibal	4	336.53	0.30	.088	4.05	"	8,975	
Kesterson	Jackson	4	367.14	0.02	.006	4.14	"	26,117.5	Explosive break.
Mueller & Geisler	Jefferson City	4	310.41	0.09	.024	4.15	"	15,680.5	Cotton rock.
"	" "	4	342.23	1.82	.533	4.06	"	9,610	Pitted dolomite. Small flakes broke off in freezing. One cracked nearly across base.
Kieselbach	" "	5	350.31	0.17	.048	4.21	"	15,145	Cotton rock. Explosive break.
"	" "	5	342.73	0.36	.106	4.15	"	11,962	Pitted dolomite.
Shoal Creek	Joplin	2	344.53	0.13	.047	4.09	"	8,111	
Casey	Kahoka	4	329.72	0.32	.096	4.12	"	11,786.2	
Lyle Rock Co.	Kansas City	4	332.66	0.24	.071	4.19	"	9,644.7	
Schlief	Koeltztown	4	362.97	1.01	.298	4.12	"	11,676.5	
Hughes Stone Co.	Noel	4	368.78	0.11	.028	4.17	"	20,472	Pieces show stratification planes.
Phenix Stone & Lime Co.	Phenix	4	353.24	0.33	.094	4.12	"	11,121.5	
" "	"	4	365.90	0.36	.097	4.18	"	12,146.5	
Peirce City Building Stone Co.	Peirce City	4	362.04	0.42	.114	4.19	"	9,028.7	
Fullerton	Princeton	4	341.92	0.27	.084	4.09	"	11,509	Lower ledge.
"	"	4	310.20	0.35	.122	4.12	"	5,029	Upper ledge broke quietly.
White	Rolla	3	316.51	3.17	.909	4.19	"	9,323.3	
Rymer Bros.	Sedalia	4	324.70	0.32	.098	4.14	"	13,627.6	Blue stone. One piece cracked in freezing.
Knapp	Sheffield	4	356.21	0.23	.064	4.13	"	14,250.7	Contained fine stratification planes.
Hollman	Springfield	4	369.28	0.13	.036	4.11	"	17,814	Show stratification planes. Wedge-shaped pyramids.
Stolle Stone Co.	St. Louis	4	341.97	0.29	.093	4.16	"	16,246	Stockton ledge.



RELATION BETWEEN LOSS IN WEIGHT AND LOSS IN STRENGTH DUE TO FREEZING TEST.

——— Loss in Strength. — — — — Loss in Weight.

(Horizontal divisions represent different stones.)

TABLE NO. IX.

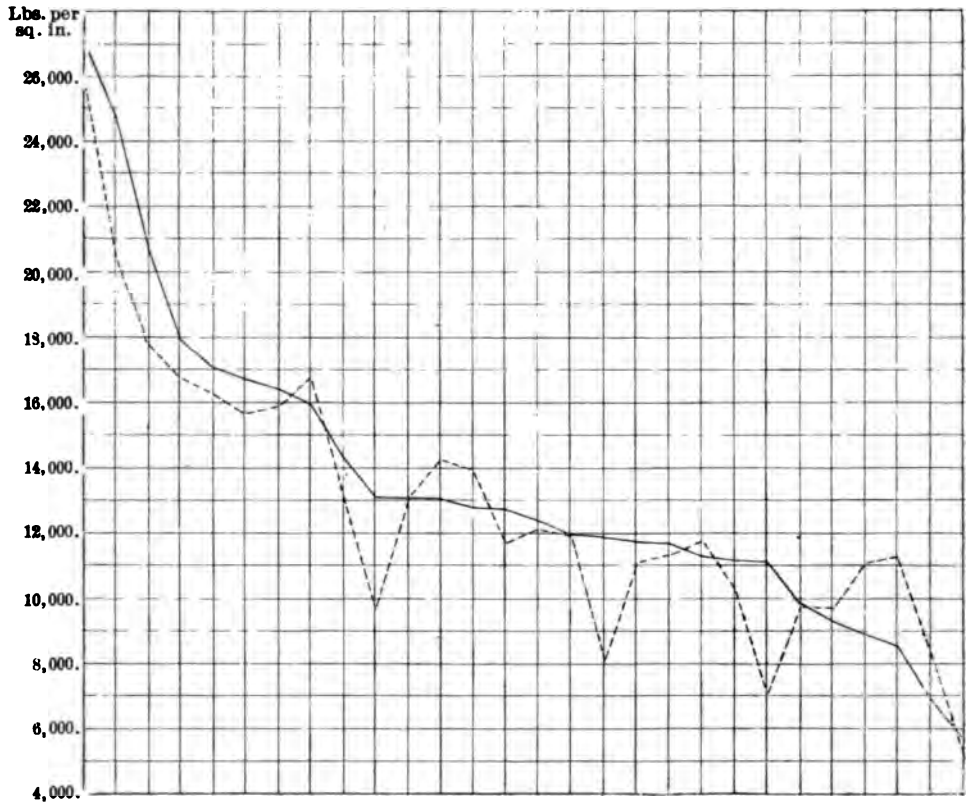
COMPARATIVE STRENGTH OF FRESH AND FROZEN SAMPLES.

LIMESTONE.

Name of quarry.	Location of quarry.	Fresh cubes. No. samples.	Fresh cubes. Av. crushing strength in lbs per sq. inch.	Frozen cubes. No. samples.	Frozen cubes. Av. crushing strength in lbs per sq. inch.	Difference in strength.	Remarks.
Butters & Son	Rowling Green	3	8,881.6	4	11,074.0	*2,192.4	
" "	" "	6	8,793.8	4	+	+	Contained well defined bedding planes
Breckenridge Stone Co	Breckenridge	2	6,944.0	4	8,163.0	*1,219.0	
Carthage Marble and White Lime Co	Carthage	3	14,270.6	4	13,382.7	887.9	
" " " " "	"	2	16,337.0	3	15,865.0	472.0	
" " " " "	"	3	12,741.3	4	13,921.0	*1,179.7	
Richardson	Columbia	2	9,828.5	2	9,738.0	90.5	
Frech	DeSoto	2	17,831.0	4	16,890.0	934.0	
Hannibal Lime Co.	Hannibal	3	9,286.3	3	8,975.0	311.3	
Kesterson	Jackson	2	27,183.0	4	26,117.5	1,065.5	
Kieselbach	Jefferson City	4	15,964.7	4	15,145.0	819.7	Cotton rock
"	" "	4	11,960.0	4	11,961.0	*11.0	Pitted dolomite
"	" "	3	16,672.3	4	15,680.5	987.8	Cotton rock
Mueller & Geisler	" "	3	11,141.0	4	9,640.0	1,501.0	Pitted dolomite
" "	Joplin	1	11,870.0	2	8,111.0	3,759.0	
Shoal Creek	Kahoka	4	11,260.0	4	11,786.2	*326.2	
Casey	Kansas City	4	13,124.0	4	9,644.7	3,479.3	
Lyle Rock Co	Koeltztown	4	12,641.0	4	11,676.5	964.5	
Schlief	Noel	4	24,661.5	4	20,472.0	4,189.0	
Hughes Stone Co	Phenix	3	11,748.3	4	11,121.5	626.8	
Phenix Stone and Lime Co	"	3	12,374.6	4	12,146.5	228.1	
" " " "	Peirce City	4	11,270.2	4	9,028.7	2,241.0	
Peirce City Building Stone Co	Princeton	3	5,714.0	4	5,029.0	685.0	Stone from the upper ledge
Fullerton	"	3	11,696.3	4	11,599.0	97.3	Stone from the lower ledge
"	Rolla	4	8,486.7	3	9,323.3	*836.6	
White	Sedalia	3	12,995.3	3	13,027.6	*32.3	
Rymer Bros	Sheffield	3	13,140.6	4	14,250.7	*1,110.1	
Knapp	Springfield	2	20,779.0	4	17,814.0	2 965.0	
Hollman	St. Louis	2	17,095.0	4	16,246.0	849.0	
Stolle Stone Co							

*Frozen samples showing an increase in strength.

†Split along bedding planes.



CRUSHING STRENGTH OF THE FRESH AND FROZEN SAMPLES.

——— Fresh Samples. — — — — Frozen Samples.

(Horizontal divisions represent different stones.)

Curless	Liberal	3	4,942.0	4	5,742.7	*599.3	
Liberal Stone and Coal Co.	"	3	4,570.6	4	3,188.7	1,181.9	
" " " "	"	3	9,002.0	4	9,230.2	*228.2	Asphaltic sandstone
Carroll County Sandstone Co.	Miami	3	7,477.6	4	8,670.5	*1,192.9	
Morris	Montrose	4	5,570.7	4	2,859.5	2,511.2	
Pickel Bros.	Warrensburg	3	5,910.6	4	5,097.5	813.1	

*Frozen samples showing an increase of strength.

TABLE NO. X.

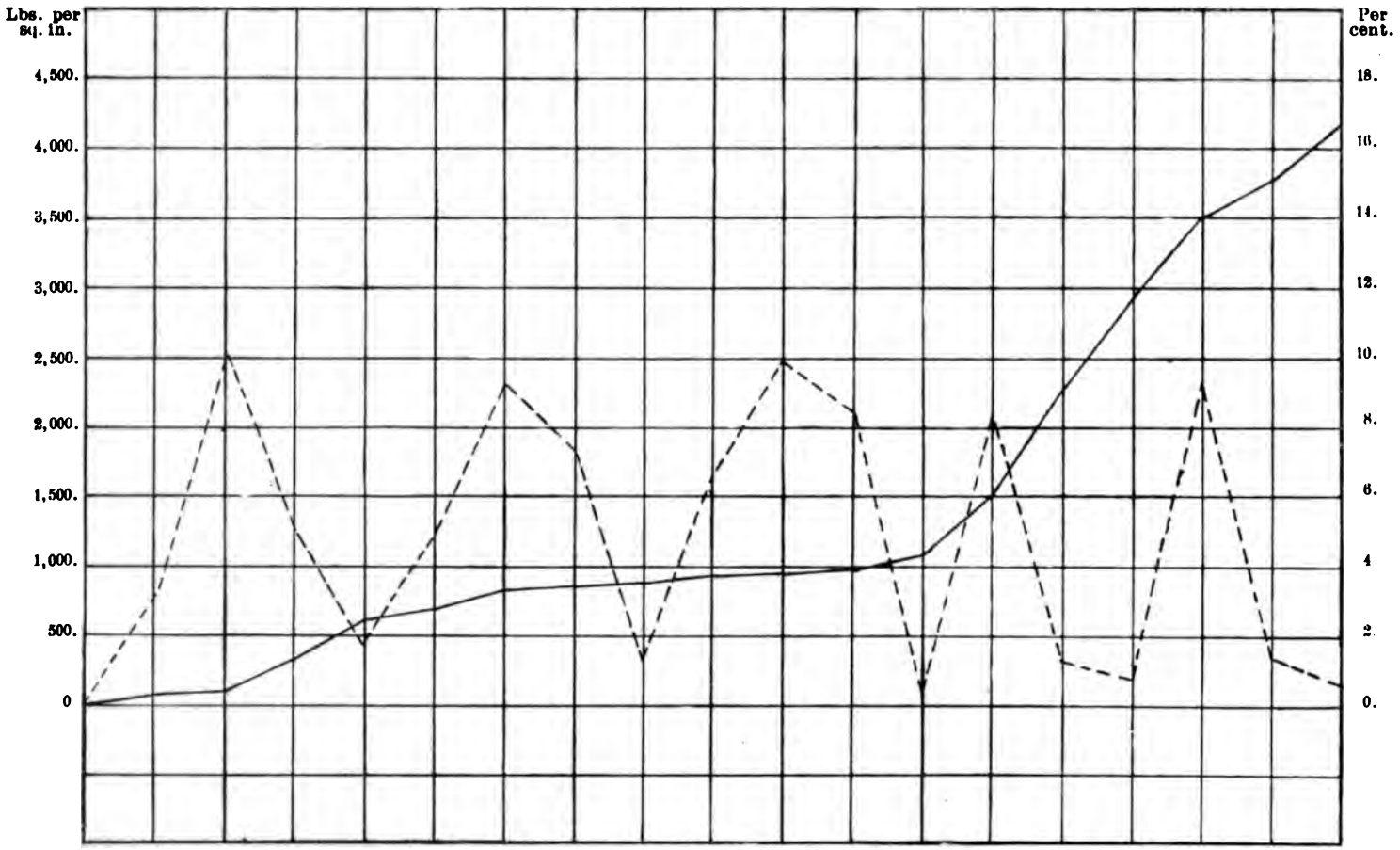
EFFECT OF SULPHUROUS ACID GAS IN A MOIST ATMOSPHERE.

LIMESTONE

Name of quarry.	Location of quarry.	Weight after drying at 110° C. before treatment. In grams.	Weight after drying at 110° C. after 96 days' treatment. In grams.	Remarks.
Butters & Son	Bowling Green			Cracked similar to cotton rock. Could not be weighed.
Breckenridge Stone Co.	Breckenridge	35.37	35.80	No evidence of deterioration.
Carthage Marble & White Lime Co.	Carthage	39.56	39.62	No change in color. No evidence of deterioration.
Frech	DeSoto	45.92	47.83	Sample swelled and cracked over entire surface. Cotton rock.
Hannibal Lime Co.	Hannibal	47.05	47.10	No evidence of deterioration.
Kesterson	Jackson	45.00	44.98	No evidence of deterioration.
Kieselbach	Jefferson City			Cotton rock. Sample swelled and cracked. Crumbled when handled.
Mueller & Giesler	"	46.69	50.65	Cotton rock. Swelled, cracked and became yellow. Weight increased.
" "	"			Pitted dolomite. Sample crumbled after swelling.
Phenix Stone & Lime Co.	Phenix	40.08	40.12	No evidence of deterioration.
Peirce City Building Stone Co.	Peirce City	44.96	45.00	No evidence of deterioration.
Fullerton	Princeton	39.68	40.22	Top ledge. No evidence of deterioration.
"	"	40.91	40.96	Lower ledge. Color intensified.
White	Rolla	40.28	41.78	Pitted dolomite. Sample broke and crumbled. Increased in weight.
Knapp	Sheffield	44.49	44.72	Took on a somewhat darker color. Bethany Falls limestone.
Stolle Stone Co.	St. Louis	41.52	42.30	Much darker color, as a result.

SANDSTONE.

Curless	Liberal	38 15	38.80	No effect
Liberal Stone & Coal Co.	"	41.30	41.25	Asphaltic sandstone. No effect.
" "	"	39.15	40.27	Buff-colored sandstone. No effect.
Carroll County Sandstone Co.	Miami	36.02	37.01	Where this stone was in contact with damp abestos it softened and was easily crumbled
Morris	Montrose	30.22	30.92	No effect
Pickel Bros.	Warrensburg	33.24	33.82	Somewhat darker



RELATION BETWEEN POROSITY AND LOSS IN STRENGTH DUE TO FREEZING TEST.

——— Loss in Crushing Strength. — — — — Porosity.

(Horizontal divisions represent different stones.)

TABLE NO. IX.

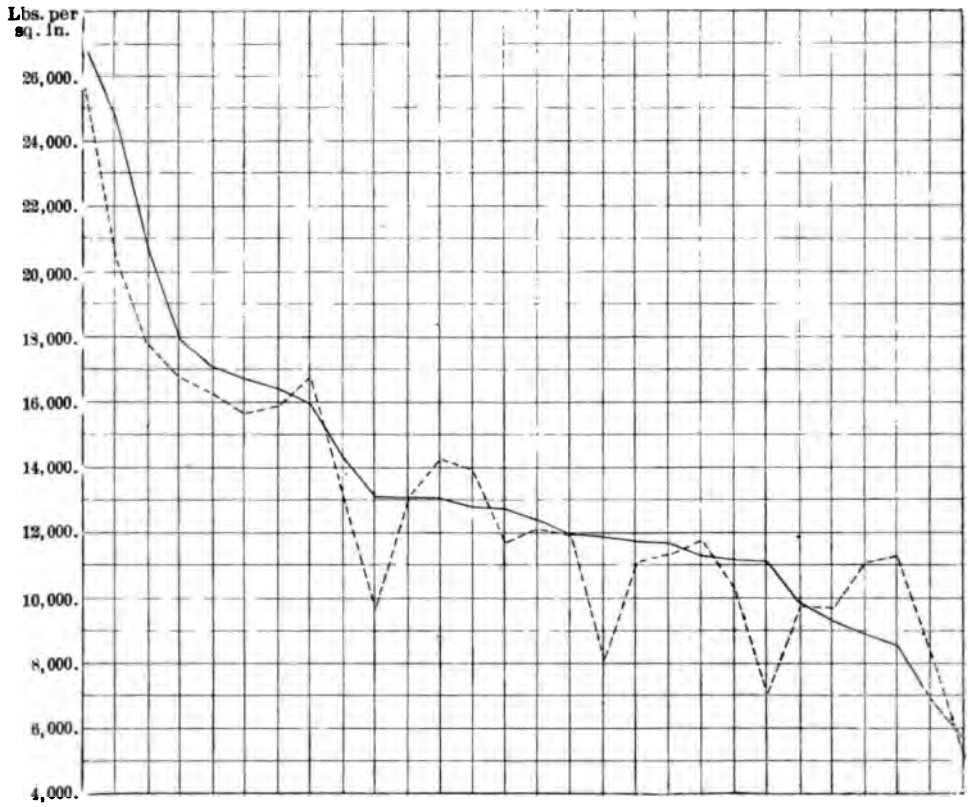
COMPARATIVE STRENGTH OF FRESH AND FROZEN SAMPLES.

LIMESTONE.

Name of quarry.	Location of quarry.	Fresh cubes. No. samples.	Fresh cubes. Av. crushing strength in lbs per sq. inch.	Frozen cubes. No. samples.	Frozen cubes. Av. crushing strength in lbs per sq. inch.	Difference in strength.	Remarks.
Butters & Son	Bowling Green	3	8,881.6	4	11,074.0	*2,192.4	
" "	" "	6	8,793.8	4	+	+	Contained well defined bedding planes
Breckenridge Stone Co	Breckenridge	2	6,944.0	4	8,163.0	*1,219.0	
Carthage Marble and White Lime Co	Carthage	3	14,270.6	4	13,382.7	887.9	
" " " " "	"	2	16,337.0	3	15,865.0	472.0	
" " " " "	"	3	12,741.3	4	13,921.0	*1,179.7	
Richardson	Columbia	2	9,828.5	2	9,738.0	90.5	
Frech	DeSoto	2	17,831.0	4	16,890.0	954.0	
Hannibal Lime Co.	Hannibal	3	9,286.3	3	8,975.0	311.3	
Kesterson	Jackson	2	27,183.0	4	26,117.5	1,065.5	
Kieselbach	Jefferson City	4	15,964.7	4	15,145.0	819.7	Cotton rock
"	" "	4	11,920.0	4	11,961.0	*11.0	Pitted dolomite
Mueller & Geisler	" "	3	16,672.3	4	15,680.5	987.8	Cotton rock
" "	" "	3	11,141.0	4	9,640.0	1,501.0	Pitted dolomite
Shoal Creek	Joplin	1	11,870.0	2	8,111.0	3,759.0	
Casey	Kahoka	4	11,260.0	4	11,786.2	*326.2	
Lyle Rock Co	Kansas City	4	13,124.0	4	9,644.7	3,479.3	
Schlief	Koeltztown	4	12,641.0	4	11,676.5	964.5	
Hughes Stone Co	Noel	4	24,661.5	4	20,472.0	4,189.0	
Phenix Stone and Lime Co	Phenix	3	11,748.3	4	11,121.5	626.9	
" " " "	"	3	12,374.6	4	12,146.5	228.1	
Peirce City Building Stone Co	Peirce City	4	11,270.2	4	9,028.7	2,241.0	
Fullerton	Princeton	3	5,714.0	4	5,029.0	685.0	Stone from the upper ledge
"	"	3	11,696.3	4	11,599.0	97.3	Stone from the lower ledge
White	Rolla	4	8,486.7	3	9,323.3	*836.6	
Rymer Bros	Sedalia	3	12,995.3	3	13,027.6	*32.3	
Knapp	Sheffield	3	13,140.6	4	14,250.7	*1,110.1	
Hollman	Springfield	2	20,779.0	4	17,814.0	2 965.0	
Stolle Stone Co	St. Louis	2	17,095.0	4	16,246.0	849.0	

*Frozen samples showing an increase in strength.

†Split along bedding planes.



CRUSHING STRENGTH OF THE FRESH AND FROZEN SAMPLES.

——— Fresh Samples. — — — — Frozen Samples.

(Horizontal divisions represent different stones.)

TABLE NO. XI—Continued.

LIMESTONE.

Name of quarry.	Location of quarry.	Crushing strength in pounds per square inch.	Specific gravity.	Porosity.	Weight per cubic foot.	Authority.
Bedford, Indiana, Stone Co.	Bedford, Indiana.	5,600	2.47	.....	154.4	21st An. Rep. of State Geologist of Indiana, 1896, p. 215.
Dunn & Co.	" "	6,500	.....	.....	147.0	" " " "
Twin Creek Stone Co.	Salem, "	9,900	2.51	.....	156.9	" " " "
Romona Oölitic Stone Co.	Romona, "	7,000	2.48	.....	155.0	" " " "
John B. Crafton	Bloomington, "	11,400	.....	.....	.....	" " p. 213.
Chicago Bedford Stone Co.	Bedford, "	9,600	.....	.....	.....	" " " "
Buff & Blue Stone Co.	Bloomington, "	6,100	.....	.....	.....	" " " "
Bedford Quarries Co.	Bedford, "	4,800	.....	.....	.....	" " " "
Bedford Oölitic Limestone	" "	4,326.7	(Av.	of 17	cubes.)	" " p. 317.
G. K. Perry	Ellettsville, "	13,500	.....	.....	.....	" " 314.
Bowers' Quarry	Knowles, Wis.	29,189	2.793	.475	166.02	Wisconsin Geol. and Natural History Survey, Bul. IV, pp. 392-401
Laurie Stone Co.	Sturgeon Bay, Wis.	31,957	2.841	.53	176.26	" " " "
Oenning & Giesen Quarry	Fountain City, "	8,830	2.804	12.18	153.69	" " " "
Voree Quarry	Burlington, "	12,066	2.781	8.36	159.01	" " " 392-402
Hersey, Staples & Hall	Stillwater, Minn.	10,750	2.69	.....	160.4	Minnesota Geol. and Natural History Survey, Vol. I, p. 196.
Brackenridge, Stewart & Butters.	Kasota, "	18,500	2.64	.....	157.4	" " " "
Eastman	Minneapolis, "	17,500	2.71	.....	165.9	" " " 200.
A. Rau	St. Paul, "	19,500	2.71	.....	164.6	" " " "
A. J. Green	Stone City, Iowa.	11,250	2.56	.....	135.9	" " " "
	Lemont, Ill.	27,000	2.78	.....	165.3	" " " "
Le Grand Quarry Co	Timber Creek, Iowa.	.....	.....	.....	.....	Iowa Geol. Suryey, Vol, VII, p. 246.
Oölite fine-grained fossiliferous limestone.	N. E. Quarry	11,600	.....	.....	.....	" " 246-250.
	N. E. Quarry	10,500	2.77	.....	173.0	" " "
	Quincy, Ill.	9,187	2.570	.....	160.5	Arkansas Geol. Survey, An. Rep. 1890, Vol. IV, p. 210.
	Lemont, Ill.	12,000	2.645	.....	165.3	" " " "
	Joliet.	14,775	2.56	.....	160.0	" " " "
	Tuckahoe, N. Y.	13,076	2.837	.....	177.6	" " " "

Ashland Brownstone Co	Presque Isle	6,244	2.637	18.57	133.99	Wis. Geol. & Natural History Survey, Bul. IV., pp. 393-402
Argyle Brownstone Co	Argyle, Wis	5,000	2.66	18.12	135.93	" " " "
Babcock & Smith	Houghton	4,166				" " " "
C. & N. W. Ry. Co	Ablemans, Wis	9,419	2.534	4.81	149.92	" " " "
Pike's Quary	Bayfield, Wis	4,588	2.632	22.62	127.13	" " " "
Prentice Brownstone Co	Houghton	4,549	2.649	19.07	133.08	" " " "
Tenino Stone Quarry Co	Tenino, Wash	5,750	2.681	18.001	136.829	Washington Geol. Survey, An. Rep., Vol. II., 1902, p. 134-135
Chuckanut	Chuckanut Bay	10,740	2.727	10.910	151.224	" " " "
W. W. Evans	Cumberland, Wash	7,400	2.681	10.607	148.641	" " " "
St. Paul & Duluth R. R	Hinckley, Minn	19,000	2.47		139.3	Minn. Geol. & Natural History Survey, Vol. I., p. 200
Tostevin & Co	Dresbach, Minn	6,500	2.38		117.5	" " " "
Philip Kipp	Jordan	3,750	2.34		113.1	" " " "
Hartley Quarry	Dakota	4,750	2.38		117	" " " "
	Berea, Ohio	10,000	2.49		131.3	" " " "
Hummelstown Brownstone	Waltonville, Pa	13,210	2.35		146.6	Appendix to An. Rep. of Penn. State College, 1896, p. 30
Lumberville Quarries	Lumberville, Pa	24,625	2.60		162.5	" " " "
Portland Quarries	Portland, Conn	12,580	2.35		146.9	" " " "
J. B. Lyne & Sons	St. Anthony, Ind	3,000				" " " "
	Fon Du Lac, Wis	4,662	2.04		127.5	" " " "

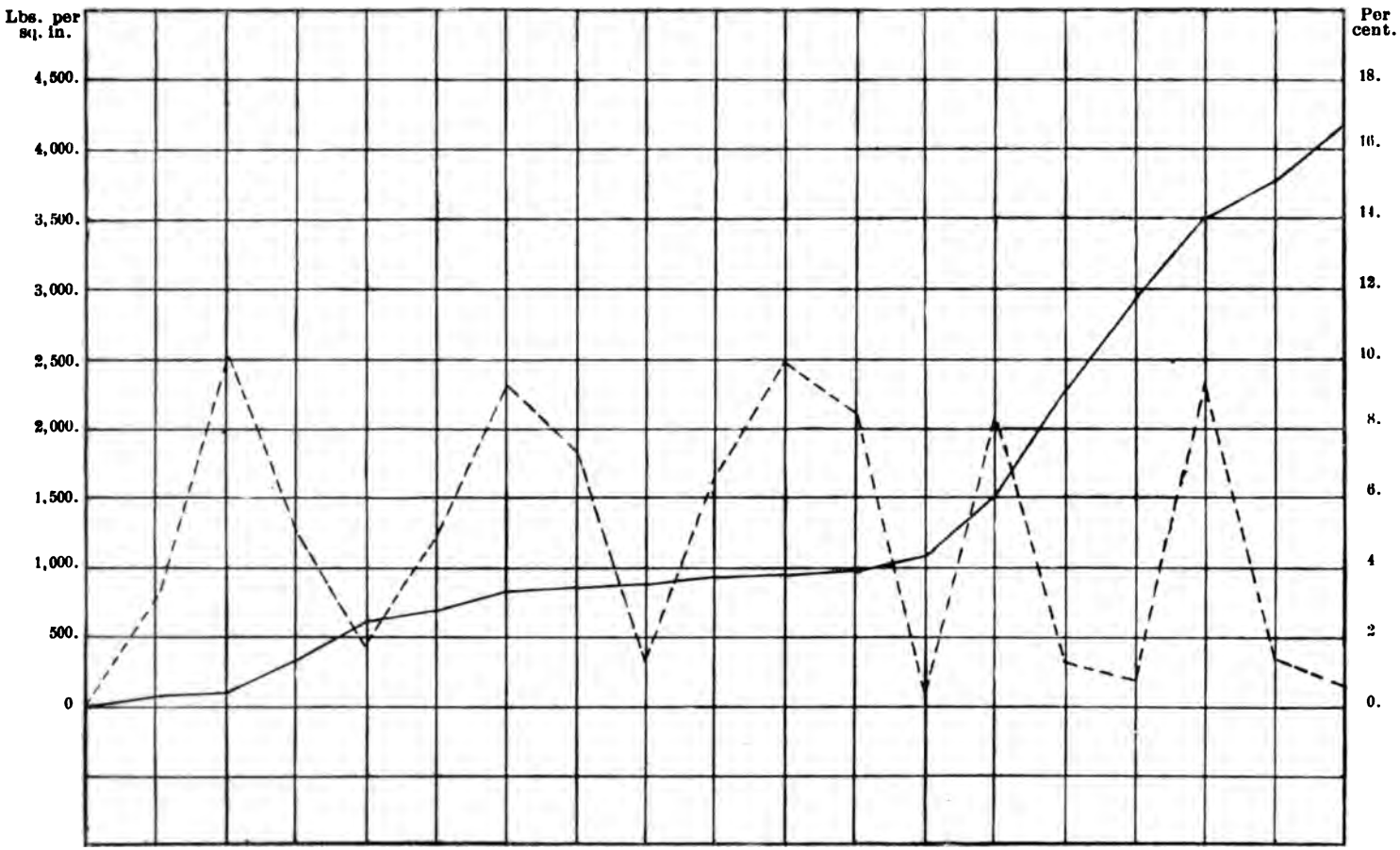
TABLE NO. XII.

PRODUCTION OF STONE IN MISSOURI FOR 1903.

Limestone.		
Rubble	194,852 perch	$230,721 00
Crushed	1,115,872 cubic yards	*265,824 19
Cut	397,042 cubic feet	285,991 97
Rip Rap	159,440 cubic yards	138,658 44
Miscellaneous uses		129,963 59
Quick Lime	1,097,281 barrels	422,781 82
Total limestone products		$2,053,941 01
Granite.		
Crushed	30,000 tons	†$30,000 00
Monumental	34,000 cubic feet	26,175 00
Spalls	1,540 tons	1,350 00
Paving Blocks	785,506	19,870 00
Curbing	13,000 feet	2,405 00
Total		$79,800 00
Tripoli.		
75,000 filters 3,180 tons ground 900 tons crude		$90,000 00
Sand.		
Glass and Moulding	114,894 tons	†$59,163 00
Sandstone.		
Miscellaneous		$34,423 17
Chats.		
Railroad Ballast	407,378 cubic yards	$203,689 00
Other uses not estimated		
Total production of quarry products		$2,521,016 18

*The railroads used 479,705 cubic yards of crushed stone, valued at $239,852.50, the greater part of which is included in the returns received above.

†Incomplete returns.



RELATION BETWEEN POROSITY AND LOSS IN STRENGTH DUE TO FREEZING TEST.

——— Loss in Crushing Strength. — — — — Porosity.

(Horizontal divisions represent different stones.)

cents or 50 cents per day in wages will affect very markedly the expense of quarrying the stone.

The cost of transportation depends altogether upon the location of the quarry with respect to the markets. If the stone has to be hauled by team several miles to the nearest station, the expense will be greater than if the quarry were located on the railroad. A quarry which is located on two competing railroads usually secures better freight rates than one which has the privilege of only a single railroad. Where there is only one line the rates are sometimes so high as to exclude the possibility of operating the quarry. As a rule, however, there is very little unfair discrimination by the railroads in Missouri. The railroad companies recognize the fact that the development of the quarrying industry contributes very greatly to their own prosperity and that exorbitant rates will eventually react to their injury. Nevertheless, we are confronted with the fact that the quarry owners in the eastern states have an advantage over the western quarry owners by having relatively lower rates of transportation. It is possible for the quarry owners in Vermont and Massachusetts to place granite on the St. Louis market at a relatively less expense to the producers than can the granite producers in the southeastern part of Missouri. This is, in a measure, due to the low freight rates given eastern producers by the railroads.

It was stated above that the sale of a stone depended in a measure upon its reputation. When a stone has had a wide and continuous sale for twenty or twenty-five years, it is said to have gained a "reputation." Sometimes an inferior stone obtains a reputation through which it commands a better price than one of better quality.

The price of dressed stone depends very largely upon the inherent qualities of the stone and the cost of labor. There is a very great difference in the ease with which a stone can be cut and dressed. A stone does not take all the different dressings with equal facility and of two different stones one may take a bush-hammered finish more readily than the other takes a rock faced finish and *vice versa*. There are some excellent building stones which are so difficult to dress that they cannot find a market. The price of labor affects the cost of dressing and an increase of 25 cents or 50 cents a day in wages may render the production of dressed stone unprofitable.

In the price of labor, both skilled and unskilled, the eastern quarries have an advantage over those located in Missouri and neighboring states. This, combined with the low freight rates, makes it possible for the eastern quarries to sell stone in the western market in competition with the local quarries.

In a new country, quarries are usually opened on a small scale, being

worked by hand. This is well enough where the stone is not intended for shipment, but where it is intended to offer the stone in the open market, improved machinery is necessary. As the demand for stone in the western and southern states increases and the people attain a better appreciation of the value of the home product, the quarries in Missouri will be better equipped and the price of stone will be correspondingly lowered.

In Chapter Eleven, there is given a table showing the comparative strength of building stones from Missouri and other states. These results are very flattering to Missouri stone, showing that the limestone and granite are equal to the very best stone obtained from the eastern quarries. The varying conditions under which the durability tests have been made in other states, renders a comparison of results rather unsatisfactory. The conditions under which experiments have been performed in the various laboratories are very different. The porosity tests are only valuable when the methods of obtaining the results are known and the size of the pore spaces is considered. Experiments have been performed to determine the loss in weight occasioned by alternate freezing and thawing, but these data are not important. Tests to determine the loss in strength resulting from alternate freezing and thawing are vastly more important, although prior to this they have only been determined in the preparation of the report on the "Building and Ornamental Stones of Wisconsin."

Many of the large public buildings, as well as hundreds of private residences in this State, have been constructed out of stone shipped from quarries outside of Missouri. Many of these buildings might have been constructed out of native stone, equal if not superior in quality. For some reason, people obtain pleasure in anything, in which "imported" materials have been used, and as long as this sentiment prevails, granite will be shipped from Scotland and gray limestone imported from our sister states. The quarrying industry in this State can be materially aided by inaugurating a sentiment, favoring the use of native stone in all buildings within the State, where the local stone is equally as good and desirable for such purposes.

A good stone costs more than one of inferior quality. Contractors, however, frequently expect the best grade of stone from one locality at the same price that an inferior stone can be obtained from another locality. The appropriation for the construction of public buildings is often too small to permit the use of the best materials. A contractor is sometimes limited in the selection of stone for private buildings by the amount of money at his disposal.

Some of the monuments erected in cemeteries will retain their inscriptions for only a few centuries. However, if they fulfill their purpose, they should withstand injury for many centuries, and irrespective of cost, they should be built out of the most durable stone. A part of the ornamentation should be sacrificed and a more durable stone purchased. Marble, which has been used for monuments so extensively in the past, is now sold mainly in the rural districts. Granite is taking its place, and it now becomes necessary to distinguish between the different kinds of granite, selecting that which is most durable. The Missouri quarries produce only red granite. This stone is well adapted for the construction of monuments, where durability is of first importance.

Everywhere one finds that durability is sacrificed for cheapness. Cheap material is used in the construction of pretentious buildings, which must be rebuilt in one or perhaps two generations. The permanent wealth of the country is always lessened by the use of poor materials. A time is coming when durability must receive more consideration and when temporary structures will only be built in newly developed portions of the country.

Many of the quarries in Missouri are in a very immature stage of development. The industry may be said to be in its infancy and we stop to ask how best to promote its development. A large part of the value of stone is in the labor, which is required to quarry, cut and dress it, making it one of the most important industries for the laboring class. The people of the State should give the industry a fair share of attention and it should be recognized in a public way. A sentiment should be inaugurated, favoring the use of native stone in all buildings where the stone is equally as desirable as that which may be imported. Quarry operators should grade their stone, permitting the use of only the best quality in places where inferior stone may prove disastrous to future trade. Unnatural competition which results in the sale of inferior stone for a better grade should never be indulged in; the quarries should be well equipped with improved machinery; and finally the people of the State should have a better appreciation of what is meant by good building stone. They ought to know that an inferior stone will eventually prove more expensive than a durable one, although the purchase price of the latter may be greater. The people ought not to be satisfied to erect public buildings out of cheap stone, but should demand that which is strong and durable. Our buildings must become more permanent if our civilization is to be what the optimistically inclined predict of it. We need permanent structures that are simple and have the beauty and solidity of a permanent civilization.

APPENDIX.

COMPOSITION AND KINDS OF STONE—ROCK STRUCTURES.*

INTRODUCTION.

In the foregoing pages, it has been necessary to use many terms which are probably unfamiliar to the general public. It is important, however, that one who desires to read this report intelligently, should have an understanding of the terms used herein. He should know the composition and origin of the different kinds of stone, and know something about the changes which they have undergone since they were formed. Everything that this chapter contains is found in the elementary text books on geology and mineralogy. These pages are therefore intended for the general public to whom, as a rule, text books on geology are not accessible. Following this introduction, the chapter takes the form of a glossary, in which the different kinds of minerals, rocks and rock structures are defined, with relation to one another. The statements made in these pages, as to the abundance, hardness, durability, importance, etc., of minerals or rocks, unless otherwise stated, refer to building stones as a class and not to rocks in general.

MINERALS.

Every rock or building stone is, as a rule, composed of several different minerals in a state of aggregation. In the case of sandstone, limestone or marble, a single kind of mineral may constitute 99 per cent. of the entire rock. It is possible to separate from a rock any one of the minerals of which it may be composed, and by chemical means determine that this mineral is made up of two or more substances known as elements. All known matter is composed of seventy-four known elements which are combined in various ways. The eight most important elements in the order of their abundance are:

Oxygen	47.13%
Silicon	27.89%
Aluminum	8.13%
Iron	4.71%
Calcium	3.53%
Sodium	2.68%
Magnesium	2.64%
Potassium	2.35%

Very few of the seventy-four elements above referred to occur free or uncombined in nature. They generally occur in combination with one another, form-

*A large part of this chapter is copied verbatim from the appendix to the report on "Building and Ornamental Stones of Wisconsin," Bul. No. 4, Wisconsin Geol. & Natural History Survey, pp. 431-460, 1898, E. R. Buckley.

ing what are known as minerals. Many of the elements are very rare, constituting a very insignificant part of the earth's crust. More than 95% of the rocks considered in this report, are composed of various combinations of fourteen minerals.

One mineral is distinguished from another by its physical properties, crystallization and chemical composition. Minerals are classified mainly on the basis of their chemical composition, and in case it is impossible to identify a mineral by its physical properties or crystallization, it must be analyzed in the laboratory. The percentage of the different elements of which it is composed, will determine its name.

Every mineral that separates from a solution or a molten magma, where growth is unobstructed, assumes a definite crystal shape. All minerals crystallize under one of six well defined systems, which are recognized by the number and relation of the plane surfaces by which they are bounded. Thus, where it is possible to determine the number of faces on any mineral and their relation to one another, we have a means of determining the mineral itself. In the case of a mineral which is a rock constituent, the crystal faces are usually wanting, and therefore this means of identification is valueless. In most sedimentary rocks, the crystal faces of the minerals are usually entirely wanting, and in many of the igneous rocks, they are either very imperfect or entirely absent. In some of the rocks, the individuals are so small that they can only be distinguished by the aid of a microscope.

It has been ascertained by careful study, that the outward crystal form is an expression of a definite internal structure. This structure imparts to each mineral certain optical properties by means of which one can, with the aid of a microscope, determine the crystal system to which it belongs and ordinarily the mineral itself. In the determination of the minerals of which a rock is composed, it is necessary to prepare very thin sections for examination with the microscope.

To one who is studying the rocks in the field, the physical properties are probably more valuable than either the crystallization or chemical composition.

The color, lustre, hardness, cleavage, and streak, are all valuable aids in the ready determination of minerals. These properties are all defined in the latter part of this chapter.

A mineral cannot always be determined by a single one of these properties, and for this reason they should be used in conjunction with one another. The important minerals and groups of minerals considered in reference to building stone, are quartz, feldspar, mica, amphibole, pyroxene, chlorite, olivine, talc, calcite, dolomite, magnetite, hematite, limonite and pyrite. Each of these will be described in the latter part of this chapter.

ROCKS.

A rock is ordinarily defined as a mineral aggregate. It consists of grains or crystals of one or more mineral species, which form a mass through their cohesion or interlocking relations with one another. Rocks are ordinarily classified on the basis of their origin into igneous, aqueous (sedimentary) and metamorphic. Although this classification is not entirely satisfactory to the student of geology, it is convenient for the purposes of this volume. The rocks of commercial importance in Missouri, may be classified as follows:

I.—Igneous;
- Granite,
- Rhyolite, (porphyry),
- Greenstone, (diabase),
- Syenite.

II.—Aqueous;
Sandstone,
Limestone (including dolomite).
Onyx.
III.—Metamorphic;
Marble,

This classification includes very few of the many different kinds of rocks which are known to geologists. These, however, are the common kinds occurring in Missouri. It must be kept in mind, that each rock type passes by insensible gradations into others of the series to which it belongs. There are all gradations between the rocks of the aqueous or sedimentary series, and between the rocks of the igneous series. Likewise, there are all gradations between igneous, aqueous and metamorphic rocks.

As the name implies, an igneous rock is one which has had its origin in the cooling and consolidation of molten magma. Provided we accept the hypothesis that the earth was at one time a molten mass, which has subsequently cooled, the igneous rocks may be either a result of the downward cooling of the earth's crust, or a result of the solidification of molten magma which has been pushed up from below, into or through the already cooled portion.

These rocks exhibit many differences in mineralogical composition and size and arrangement of the grains, as a result of the varying conditions under which the molten material solidified, combined with differences in the chemical composition of the original magma. Based upon the chemical and mineralogical compositions and upon the size and arrangement of the individual particles, there have arisen a number of different classifications of igneous rocks. It would be entirely out of place to describe the many different kinds of rock included in any one of these classifications of igneous rocks. In the latter part of this chapter there will be found a description of the kinds of rocks used for building and ornamental purposes in Missouri.

The aqueous or sedimentary rocks have their origin in chemical or organic precipitation and mechanical deposition from water. Were it possible to trace the minerals composing the sedimentary rocks to their original sources, one would find that they have been in a large part, derived from the igneous rocks. A hole drilled or dug into the ground anywhere, will eventually pass through the sedimentary rocks and enter those of igneous origin. Wherever a sedimentary rock may occur today, we may be sure that at an earlier time in the world's history there was one of igneous origin.

The sedimentary rocks are worked-over material derived from igneous rocks. Weathering and erosion have been active for millions of years, breaking down the rocks at the surface of the earth. The rivers are constantly transporting millions and millions of tons of rock flour from the continents into the oceans. Millions of tons of rock are also being taken into solution and in this way removed from the continent. The waves that beat upon the shore, are steadily breaking down the cliffs and transforming them into sand and gravel. The shore currents, waves and tides, pick up and assort this material, and that which is brought into the ocean by the rivers, depositing it over the bed of the ocean near the land. The coarsest material is dropped nearest the shore, while the finer is carried into deeper water.

The ocean is inhabited by myriads of animals and plants that are continually extracting calcium carbonate and silica from the water to build their shells and skeletons. As these creatures die, their remains are added to the accumulations of sediment, and in many places, these are so abundant as to form a large part of the deposit. Besides calcium carbonate and silica, which are the principal sub-

stances used in building the shells of marine animals, the water carries in solution other soluble salts which are often precipitated to the bottom of the ocean, mingling with the mechanical sediments and organic remains.

Through these various agencies, four principal kinds of sediments are formed, conglomerate, sandstone, shale and limestone (including dolomite). These deposits form the sedimentary rocks, and between them, one may find every possible gradation.

The metamorphic rocks are rocks of both the igneous and sedimentary series, which have been profoundly altered through dynamic and other agencies since they were first formed. Every igneous and aqueous rock has its equivalent in the metamorphic series. The most abundant metamorphic rocks are gneisses, which may be either altered igneous or altered aqueous rocks; quartzite, which results from the induration of sandstone; and marble which is the metamorphosed equivalent of limestone.

The only metamorphic rock used as a building stone in Missouri is marble. Quartzite occurs in a few localities, but it is not sufficiently abundant or in large enough dimensions to constitute a material for building or ornamental purposes.

ROCK STRUCTURES.

The structures which are recognized in sedimentary and igneous rocks, are either original or secondary in origin. Original structures in sedimentary rocks are those which have been produced through changing conditions of sedimentation, or alternation of sediments. Through the alternation of sediments, there is formed a structure which is called *stratification.* Originally, the sedimentary rocks possess no actual parting planes, but merely stratification, which is a plane along which the rock has a natural capacity to part most readily. The degree to which this capacity is developed in a sedimentary rock, will depend upon the kind of sediments and the abruptness of change from one to another.

The igneous rocks which have been formed deep below the surface of the earth were originally massive and homogeneous and without original parting planes. Igneous rocks, which have solidified at or near the surface, often have an original flowage structure which resembles in some respects the stratification of the sedimentary rocks. These have a capacity to part most readily along the flowage planes.

All rocks at or near the surface of the earth, exhibit secondary structures. One ordinarily thinks of the rock envelope at the surface of the earth as being a continuous, unbroken mass of rock. However, when closely examined, it is found to be composed of a mass of various sized, polygonal blocks, to all appearances perfectly fitted to each other. These blocks have a wide range in size, being from a few inches to fifty or even several hundred feet in cross section.

The parting planes by which these blocks are bounded, have been produced during or since the consolidation of the rocks, chiefly as a result of compressive and tensile stresses, either simple or complex. The commonest and most important of these parting planes are joints which develop in sedimentary, igneous and metamorphic rocks, alike. The relief from stresses in the earth's crust generally takes place along planes of weakness. In the sedimentary rocks, the stratification planes are planes of weakness along which actual parting takes place. These planes might consistently be called joints, but owing to their parallelism with stratification, they are known as *bedding*, in distinction from those planes that are normal or inclined to the stratification.

Parting planes may be developed in two or more directions, normal or inclined to bedding. These fractures are known as joints, although usually spoken of by quarrymen, as vertical or inclined seams. Joints which are normal or inclined to

bedding, usually occur in sets almost at right angles to each other. They are ordinarily classified as "dip" joints and "strike" joints, depending upon whether they correspond in direction with that of the strike or the dip of the rocks. In the classificaion of joints, it would be better to consider them as tension and compression joints, as suggested by VanHise*. The classification into dip and strike joints, is unsatisfactory, in so much as it fails to provide for the possible cases. The classification into tension and compression joints, is based upon origin and is therefore thought to be more appropriate. However, this is not of sufficient importance to warrant a discussion in this place.

Quarrymen frequently speak of joints as "major" and "minor," depending upon the length and depth to which they have been developed. Major joints are those seams which continue to a considerable depth and for long distances. Minor joints are those seams which originate and die out within short distances usually within the same quarry. One frequently finds in the Missouri stone short, tight seams, which are known to the quarrymen as "dries" or "incipient joints." These have, in some cases, apparently been formed by a torsional movement in the rock. Sometimes the dries are not over a few inches deep and from 10 to 12 inches long. Near the surface the rock along the major joints has often been removed by solution forming narrow V shaped trenches, sometimes 40 feet in depth. These are usually filled with mud and clay and are known to the quarrymen, as mud seams.

The jointing in the igneous rocks is usually more complex than in the sedimentaries. Bedding always occurs in the sedimentary rocks and the joints are mainly vertical, dipping only a few degrees. The igneous rocks in Missouri are older than any of the sedimentaries, and have been subjected for a greater length of time to the tensile and compressive stresses, which are active in the crust of the earth. The joints are partly vertical, but many of them are inclined or even approximately horizontal. Horizontal or nearly horizontal joints, occur in the igneous rocks, corresponding to the bedding planes in the sedimentaries. These bedding planes may occur either along the flowage planes of surface lavas, or in the originally structureless deep seated rocks, such as granite.

Quarrymen are, as a rule, familiar with the advantages and disadvantages of well developed bedding and jointing planes. These parting planes may occur in such a manner as to furnish blocks of a convenient size or they may be so far apart as to be of no assistance in quarrying. Again they may be so abundant as to break the stone into blocks, which are too small for building or other constructional purposes. In case the stone in a quarry is broken into small blocks by bedding and jointing planes, it can usually be handled very economically for the manufacture of crushed stone, or in the case of suitable limestone for the manufacture of quicklime. Where the stone is desired for heavy constructional work, the presence of numerous joints is a source of great annoyance and expense to the quarrymen. A combination of vertical and inclined joints, even though the latter are relatively few, is often the cause of considerable waste in a quarry. Vertical joints occurring alone are the most desirable for the profitable exploitation of stone for building purposes. The "dries," referred to above, are a source of very great annoyance and occasion a considerable amount of waste in some quarries.

As a rule, the joints occur in pairs which strike nearly at right angles to each other. A series of parallel jointing planes are usually spoken of as a set of joints. It is usual to find two sets of joints striking nearly at right angles to each other. Frequently, four sets are found, but seldom more than two of these are vertical

*Principles of North American pre-Cambrian Geology, by C. R. VanHise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, pp. 668-672.

the others are usually inclined. Joints are frequently very abundant in one part of a quarry and sparse in another. Curved joints are common, occurring both in the sedimentary and igneous rocks.

Other structures known as faulting, folding, cleavage, schistosity and fissility, are produced in rocks. Where beds are arched or bent so as to resemble the waves of the ocean, they are said to be folded. Where these folds are very minute, they are called plications. Where movement has occurred along jointing planes, and the rocks on one side have been moved up or down with respect to the other, the parting plane is known as a fault.

Cleavage has been defined as a capacity which a rock may possess to split readily into thin laminae or folia. This structure is somewhat homologous to stratification, but is distinguished from it by being a secondary and not an original structure. The parting along cleavage planes, is sometimes smooth and at other times wavy. The former is known as slatiness or slaty cleavage and the latter as schistosity. Prof. VanHise,* has made a distinction between cleavage and fissility. He defines cleavage as "a capacity present in some rocks to break in certain directions more easily than in others." Fissility, he defines as "a structure in some rocks, by virtue of which they are already separated into parallel laminae in a state of nature."

In certaian igneous rocks there is developed, either originally or secondarily, a differential parting capacity in three directions. This is exhibited mainly in certain of the rhyolites, in which the large porphyritic individuals have been clongated and flattened in a common direction. The plane of flattening is the direction of easiest parting and is known as the "rift." The plane normal to this and extending in the direction of elongation, has been designated the "run." The third plane normal to the other two, is known as the "head." In the granite quarries of Missouri, the plane parallel to the surface or floor of the quarry, is known as the "lift."

In general it should be noted that the igneous rocks or their metamorphosed equivalents have structures which are in most respects analogous to those in the sedimentary rocks including stratification, bedding, jointing, faulting, folding, schistosity, fissility and cleavage. It is important that one who is working in a quarry, should be familiar with the above structures, as a knowledge of their manner of occurrence may often assist in the extraction of the stone.

GLOSSARY.

Amphibole.—The mineral species included under the general name of amphibole are composed mainly of magnesium, calcium, silicon, iron, manganese, and oxygen, with or without aluminum. The most common species are actinolite, in which aluminum is wanting, and hornblende in which aluminum is present. The hardness of these minerals is about that of apatite or feldspar, being from 5 to 6 in the scale of hardness. Actinolite, as often found in the igneous rocks, occurs in long needle-shaped crystals, while hornblende is columnar. The color of these varieties is usually green, brown, or black. Other varieties of amphibole are colorless to silver gray. The minerals of this group differ from those of the pyroxene group only in their mode of crystallization. For this reason it is often difficult to distinguish them from each other. The prismatic cleavage is the most useful distinguishing characteristic. In the amphiboles the angles of intersection are 124° 30′ and 55° 30′, while in the pyroxenes the angles are uniformly nearly 90°. The cleavage faces have a vitreous to pearly luster.

**Principles of North America Pre-Cambrian Geology, by C. R. VanHise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, p. 623.

Amphibole is an essential constituent of many granites, but more especially of the basic igneous rocks. It is also an abundant constituent of many schists and altered sedimentaries. The alteration products of amphibole depend upon the species under consideration, but they consist mainly of talc, calcite, chlorite, epidote and quartz. These minerals, in turn, may be still further decomposed, as in the case of chlorite, which breaks up into "a mixture of carbonates, clay, limonite and quartz." (Rosenbusch.) Under ordinary conditions at the surface of the earth, actinolite is a more stable compound than common hornblende.*

Bed.—As used in this report, a bed is considered as that portion of an outcrop or face of a quarry which occurs between two bedding planes.

Bedding.—This is a plane parallel to stratification along which actual parting has taken place. It is distinguished from stratification in that the latter is simply a plane of weakness along which the rock has a capacity to part.

Boss.—This term is popularly used to apply to large outcrops of igneous rocks, having an oval or roundish form, as exposed at the surface.

Calcite.—Calcite is composed of the elements calcium, carbon and oxygen. It is more accurately known as calcium carbonate ($CaCO_3$). The hardness is 3. Calcite is sometimes clear and transparent, but is more often white or cloudy. It sometimes contains impurities which impart a brown or pink color. It has a perfect cleavage in three directions, by means of which it breaks into small six-sided pieces, with inclined faces, called rhombohedrons.

Calcite is often mistaken by the inexperienced for quartz. The color of the two minerals is almost identical, but if one will bear in mind that the hardness of calcite is 3 and that of quartz 7, there can be little danger of confusion. Furthermore, calcite has the perfect cleavage, above mentioned, which is not present in quartz. Calcite is an essential constituent of all limestones and many sandstones. It is also a constituent of many of the igneous rocks, being an alteration product of other minerals. The only important alteration product of calcite is gypsum or the sulphate of calcium. According to Geikie, sulphate of calcium frequently forms as an outer crust on marble tombstones, due to the action of sulphuric acid. It is not known how general this product may be, but it appears very probable that the efflorescence observed on many limestones may be due to the formation of calcium sulphate.

Chert.—Chert is a variety of quartz and is composed of silicon and oxygen and has the formula SiO_2. Strictly speaking, it is a variety of hornstone which resembles flint, but having a more splintery fracture and being more brittle. As ordinarily used, chert and flint are synonymous terms. Chert occurs chiefly in the limestone formations and is probably both original and secondary. It occurs in irregular layers and nodules, which vary greatly both in shape and size. Chert is much harder than the associated limestone, being seven in the scale of hardness. It usually breaks with a conchoidal or splintery fracture and has a sharp cutting edge. It usually has a white, buff, bluish gray or some intermediate color. It frequently disintegrates, forming a white powder known locally as "chalk," "silica," or "tripoli."

Chlorite.—This group of minerals, in which is included a number of species, is composed of various combinations and proportions of magnesium, iron, manganese and aluminum, with hydrogen, silicon and oxygen.

The hardness of the minerals of this group ranges from 2 to 2.7. The members of the chlorite group are characterized by their green color, which is common to silicates containing ferrous iron. In itself, chlorite is generally an alteration product of some other mineral. It occurs in fibers and folia in many of the

*It must be understood that all the changes referred to take place very slowly.

old igneous rocks known as "greenstone," in which case it is generally an alteration product of amphibole, pyroxene, feldspar or mica. Chlorite alters to a mixture of carbonates, clay, limonite and quartz.

Clay.—This term is commonly applied to any mass of earth or shale used in the manufacture of clay wares. It has no well defined chemical or mineralogical composition. As used in reference to rocks, it applies to the mineral kaolinite to which the reader is referred.

Cleavage.—As defined by VanHise, cleavage is "a capacity present in some rocks to break in certain directions more easily than in others." This structure is discussed along with others in the first part of this chapter.

The capacity which some minerals have to part more readily in certain directions than in others is known as cleavage. A mineral may possess cleavage in one or several directions. It may be well developed in one mineral and poorly developed in others. The presence of cleavage, its perfection, and its relation to the different faces of the crystal often furnish a valuable means of identification.

Color.—For a discussion of color in rocks, reference should be made to Chapter II of this report where the subject is discussed in full.

Concretion.—Concretions are roundish nodules which consist of distinct concentric layers, ordinarily clay. They are usually an aggregation of mineral matter formed around a center. A rock mass which exhibits distinct concentric layers is referred to as having a concretionary structure.

Conglomerate.—Close to the shore line the coarser pebbles and boulders, which have been worn away from the cliffs of the adjacent coast, are laid down. These pebbles are generally well rounded, and in the spaces between the individuals finer material settles until the whole becomes a compact, solid mass. This interstitial material is known as the matrix, and is generally either sand or clay. When such a deposit has been buried underneath many thousands of feet of other sediments, it becomes consolidated and forms a rock called conglomerate. After many centuries, through elevation and subsequent wasting away of the land, the conglomerate thus formed may emerge again at the surface as a part of the continental land mass.

Where the pebbles are comparatively uniform in size a conglomerate is sometimes used for building purposes. But, as a rule, the decided difference in texture and hardness between the different pebbles and between the pebbles and the matrix, is a fatal objection to its use as a building stone. It sometimes serves as a beautiful stone for inside ornamental work, where it is protected from the destructive action of the weather. There are no conglomerates in this State of recognized economic value, and we shall therefore pass them without further discussion.

Diabase.—Diabase is one of the least abundant igneous rocks in Missouri, being found chiefly in dikes in the granite bosses. It is formed originally within the crust of the earth, and is distinguished from the other members of the family by the texture known as ophitic. This texture may be either macroscopic or microscopic. The rock is usually fine to medium grained, and seldom has a porphyritic texture. It is generally compact and thoroughly homogeneous. The color of diabase is decidedly somber, being dark green and sometimes almost black.

Dike.—A dike is a sheet of igneous rock intruded into other rocks along a fissure, usually normal or inclined to the plane of the horizon. When a sheet of igneous rock is intruded between beds of rock which are horizontal it is called a sill.

Dolomite.—See under limestone.

Dries.—This is a term used by quarrymen and refers to short, tight seams in the rocks. This, along with other structures, is discussed in detail in the first part of this chapter.

Feldspar.—The feldspar group contains two series of minerals, under both of which are included several species and sub-species. Certain of the species differ

in the elements which enter into their composition, while others merely in the percentage of such elements. The two series of minerals are known by the name of their most common member, as orthoclase and plagioclase. Orthoclase is composed of an admixture of potassium, aluminium, silicon and oxygen, with occasionally a small percentage of sodium, $(K, Na)_2 Al_2Si_6O_{16}$(Hintze). Plagioclase contains sodium, calcium, aluminium, silicon, and oxygen, with either one of the following or some intermediate formula: $Na_2Al_2Si_6O_{16}$ — $Ca_2Al_4Si_4O_{16}$. The two series differ not only in chemical composition, but also in their habit of crystallization. The former crystallizes in what is known as the monoclinic system, while the latter crystallizes in the triclinic system.

A few characteristics will suffice to distinguish them from other associated minerals. The color is generally either pink or white. The hardness is six in the scale, being surpassed, among the common minerals, only by quartz. They have two very pronounced cleavages at right angles to each other, in consequence of which they generally have smooth, glistening faces. Feldspar is not as widespread or abundant a constituent of building stones as quartz. It is found mainly in the igneous rocks, although it is often a subordinate constituent of sandstone. It is an essential constituent of granite, gneiss, porphyry, and many of the allied rocks. In fact, it is seldom absent from any of the igneous rocks.

Feldspar is a compound which is decomposed and taken into solution with less difficulty than quartz, and is seldom found in the ancient rocks in an entirely unaltered condition. Its ready cleavage permits of an easier passage of water in and through its entire mass, presenting favorable conditions for slow chemical changes. The molecules are in some manner slowly broken down, and we have formed from the feldspar by a rearrangement and recombination of the elements, a variety of different products, among which may be mentioned kaolin, quartz, chlorite, mica, epidote, zoisite and calcite. Decomposition of the feldspar takes place wherever it is exposed to the action of percolating water or to the weathering action of the atmosphere. In some manner these alterations, however slowly they act, must eventually effect the strength and durability of the rock of which the feldspar forms a part.

Fissility.—Fissility has been defined by Prof. VanHise as "a structure in some rocks by virtue of which they are already separated into parallel laminae in a state of nature." This structure is discussed in detail in the first part of this chapter.

Flint.—The composition of flint is the same as that of quartz, being SiO_2. It is one of the cryptocrystalline varieties and is closely allied to chalcedony. It varies in color from grayish blue to brownish black when unaltered. It breaks with a conchoidal fracture and has a sharp cutting edge. As commonly used, the term flint is applied to the chert associated with the limestone and dolomite formations in the State. The terms flint and chert are used interchangeably, although technically they are somewhat different.

Folding.—Folding is applied to rocks or strata which have been bent into domes and basins or rolls. This structure is observed mainly in mountainous regions, and is characteristic of both the altered and unaltered sedimentary rocks. The rocks of the Ozark plateau are in places gently folded.

Granite.—Granite is supposed to form deep below the surface of the earth, under peculiar conditions of heat and pressure, whereby the elements of the molten magma are allowed to enter into various combinations, forming minerals having definite characteristics. The rock thus formed is completely crystalline, and composed of the essential constituents quartz, orthoclase, and one or more minerals from the mica, pyroxene, or amphibole series. Plagioclase feldspar, magnetite, pyrite, zircon, apatite, and a number of less important microscopic minerals are present as accessory constituents. The minerals, as a rule, have irregular out-

lines and interlock in a very intricate manner, each of the individuals having very much the appearance of being irregularly dovetailed into those adjacent. This interlocking character of the minerals accounts for the fact, that as a rule, an individual can only be separated from the mass of the rock by severing it at some part. This characteristic of igneous rocks also accounts, in part, for their strength and the difficulty which stone-cutters experience in working them.

In certain of the granites the essential mineral constituents are very small, being distinguishable only by the aid of a lens. Such a granite is generally designated as fine grained. In others the essential constituents are often as much as a quarter or even a half an inch in diameter. These are spoken of as being either coarse or very coarse grained. Between the two extremes there are all degrees of coarseness (or fineness). Frequently a granite is found in which certain of the feldspar individuals are very large and stand out boldly in a fine grained groundmass. Such a rock is called a porphyritic granite.

Granites are discriminated from one another by the predominant ferro-magnesian mineral among their constituents, and are known as biotite-granite, muscovite-granite, hornblende-granite, augite-granite, etc.

The color of granite differs greatly in different localities. The color depends, not alone upon the color of the individual minerals composing the rock, but also upon the size and distribution of the constituents. With respect to color, granites may be classified as red and gray. Whether a granite belongs to the first or second class will depend upon the red or white color of the feldspar. Many granites contain both red and white feldspar, but so long as the red variety is sufficiently abundant to impart a reddish tint to the rock it is called a red granite. The most brilliant red granites have a preponderance of medium-sized red feldspar individuals. As the individuals become finer grained and biotite, amphibole or pyroxene become more abundant, the color is subdued and we have a dull red granite.

The gray granites are dark or light colored, depending upon the size of the individual minerals and the amount and kind of the ferro-magnesian minerals present. The lightest colored granite has a preponderance of white feldspar and contains muscovite as the main ferro-magnesian mineral. The darker gray granites contain less feldspar and a greater abundance of biotite, hornblende, or pyroxene. Occasionally one finds a granite which has a peculiar iridescent hue, which is due to the presence of one of the plagioclase feldspars, usually labradorite.

Granite is generally massive, but occasionally one finds a quarry in which the rock splits in one direction much more readily than in others. This direction is known by quarrymen as the rift. When it becomes very pronounced and wavy the granite is known as a gneiss, and should be classified under the metamorphic series.

Granite is fresh or altered, depending upon the state of preservation of the mineral constituents. The more common alterations to which the various rock forming minerals are subject are mentioned in connection with the descriptions of the different minerals. One can readily see that the alteration and decomposition of the individual minerals would, in time, result in the breaking down or crumbling of the rock itself.

Greenstone.—In the nomenclature of igneous rocks the name "greenstone" has no definite significance, having been applied to almost any rock which has a green color. The main kinds of greenstone are known as diabase, gabbro, and basalt. These rocks have, as their main constituents, plagioclase feldspar, amphibole, mica and pyroxene. All of the three last may or may not be present. To these essential constituents may be added from ten to twelve accessory minerals, some of which are present in each kind of rock.

It will be noted that the constituents of the greenstones are among the more readily decomposed and disintegrated minerals. For this reason, and on account of the dark, sombre color of the rock, they are not generally sought after as building stones.

Hardness.—The hardness of a mineral is relatively constant. For convenience, all minerals are referred to a scale of hardness of ten units composed of common or well known minerals which are as follows: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) orthoclase; (7) quartz; (8) topaz; (9) sapphire; and (10) diamond. The hardness of any mineral is determined by its ability to scratch the members of this scale. The degree of hardness is expressed by the number of the mineral in the scale, and minerals of intermediate hardness are expressed by fractions.

Hematite.—Hematite, or iron sesquioxide, is composed of iron and oxygen, but the proportion of the two elements is different from that in magnetite. The chemical composition of hematite is Fe_2O_3. It has a metallic luster. The streak is red. The color is generally steel gray to iron black, but as a rock constituent it often occurs in minute blood-red flakes. Besides occurring as a rock constituent, it is often discovered in massive beds, forming one of the most valuable iron ores. It often occurs as a cementing material in sandstone, binding together the individual grains, and with limonite, is generally the cause of the brown and red color of the sedimentary, igneous and metamorphic rocks. Hematite hydrates very slowly to limonite.

Joints.—Joints are parting planes, by which the rocks near the surface of the earth are separated into polygonal blocks. This structure is discussed in detail in the first part of this chapter.

Kaolinite.—Kaolinite is a hydrosilicate having the composition $H_4Al_2Si_2O_9$. It has a very perfect cleavage and usually occurs in flexible scales or plates. It has a hardness of 2 to 2.5 and a specific gravity 2.3-2.63. It has a white, grayish white, yellowish, and sometimes brownish or reddish color. It is usually plastic.

It occurs in large quantities as a decomposition product of granite and is often more or less mixed with quartz. It is widely distributed in small quantities through the igneous and sedimentary rocks, being present in grains and scales. It is usually an alteration product of feldspar and is commonly found associated with the old feldspathic igneous rocks.

Layer.—This term is applied to a bed or stratum of rock.

Ledge.—The term ledge is ordinarily applied to several beds of rock occurring in a quarry. In some instances, however, the term is applied to a single bed. In this report an attempt has been made to confine its use to an outcrop consisting of two or more beds.

Lift.—This is the plane approximately parallel to the floor of the quarry, along which the stone is usually split in quarrying.

Limestone.—In the ocean, beyond where the clay is deposited, calcium carbonate or calcium magnesium carbonate ($CaCO_3$ or $(CaMg)\ CO_3$) is usually deposited. This deposit is composed mainly of the shells of marine animals and calcium carbonate resulting from chemical precipitation. This deposit, as in the case of those previously described, is consolidated and transformed into rock through the pressure of superincumbent deposits and the addition of cementing material from percolating water. This rock may be brought to the surface as a part of the land area, and is known either as limestone or dolomite, depending upon the percentage of magnesium carbonate in its composition.

The method of formation of dolomitic limestone has been the subject of a great deal of discussion. Some authorities attribute it entirely to secondary processes after the limestone is deposited, while others assert that it can only be accounted for by contemporaneous chemical precipitation and the extraction from

the water of (CaMg) CO_3 by living organisms. The probability is that both original and secondary processes have contributed to its formation. In one place chemical precipitation may have been the chief agent, while in another it may have been the result of secondary processes. In other places both agencies may have been equally operative.

The chemical composition of pure limestone is calcium carbonate, a combination of the elements calcium, carbon and oxygen. Among the other constituents may be mentioned magnesium, silica, clay, iron oxide and bitumen, all of which are of common occurrence. By far the most abundant of these constituents is magnesium in the form of dolomite (CaMg) CO_3.

Owing to the presence of magnesium in large quantities in certain of the limestones, authors have been accustomed to apply the name dolomite to limestone which contains a certain percentage of $MgCO_3$, ranging from 18 per cent. to 40 per cent., depending upon the writer. The term dolomite has such a varied meaning and has been used so loosely by different authors, that it would avoid confusion if some definite usage for it was established in the nomenclature of rocks. For scientific, as well as practical purposes, it would be best, as far as possible, to distinguish limestone and dolomite as different kinds of rock. If the rock is essentially pure calcium carbonate, it should be called a limestone. If the rock is essentially calcium-magnesium carbonate, it should be termed a dolomite. If the dolomite becomes important, but not predominant, the limestone should be known as magnesium limestone. If the percentage of calcium carbonate is less than that of the calcium-magnesium carbonate the rock should be called a calcareous dolomite.

There are all gradations between the rocks in which the chemical composition is pure limestone (calcium carbonate), and those in which the chemical composition is pure dolomite. The stone may be a limestone, a magnesian limestone, a calcareous dolomite, or a dolomite. Either may be qualified by affixing the name of the most abundant subordinate constituent. If this subordinate constituent chances to be clay, the rock would be an argillaceous limestone or dolomite; if bitumen, a bituminous limestone or dolomite. Silica often occurs either as original grains of quartz or as a product of infiltration. It may be almost equal in importance to that of calcium carbonate and in such case the rock might with equal propriety be called an arenaceous limestone or a calcareous sandstone. Iron is frequently a subordinate constituent, occurring either as the carbonate, oxide or sulphide. If present in any considerable quantity the rock is known as a ferruginous limestone. Iron is a cause of the discoloration of many of the limestones after they are placed in the walls and buildings. Iron oxide, in the ferric form, is not liable to cause discoloration after the stone is placed in the wall. When iron is present as the carbonate or sulphide, it may, in the case of limestone, not only be a cause of discoloration, but it may also weaken the rock. The sulphide of iron, as described in this chapter, occurs in the form of pyrite and marcasite. Hopkins, in his report on the marbles of Arkansas (p. 60) says: "The sulphide of iron is more liable to decomposition when it is in the form of marcasite than in the form of pyrite, and is less destructive in dry places than in moist ones, as in the presence of moisture it not only forms the oxide, known as iron rust, but it at the same time produces sulphurous and sulphuric acids which act on the lime, changing it to sulphate of lime or gypsum. Often the only effect of iron, if present in very small quantities, is to mellow the stone, producing a yellow tint with age."

Clay may occur in the limestone either as thin laminae between the layers, as seggregations or disseminated in fine particles throughout the stone. An admixture of clay has a tendency to soften the limestone, thereby making it less durable. If present in thin laminae or in pockets it will soon be noticeable by

the greater rapidity with which it weathers. The surface will wear unevenly and soon become ragged and pitted.

Bitumen, either as petroleum or carbonaceous matter, is often an accessory constituent and imparts to the rock a black color and a fetid odor. The injurious effect of bitumen depends largely upon the amount present. It is objectionable, in any considerable quantity, for buildings, on account of its odor and the discoloration which it occasions. In case the stone contains from twelve to fifteen per cent of bitumen it often becomes valuable as a paving material, being used in the construction of rock asphalt pavements.

Frequently limestone formations are reservoirs of great mineral wealth. Lead, zinc, copper and mineral fuels are found in limestone formations.

Limonite.—The chemical composition of limonite is the same as that of hematite, with the exception that it contains water in addition to iron and oxygen, ($Fe_2 O_3$ + 1-½ $H_2 O$). It is found in all kinds of rocks—eruptive, sedimentary, and metamorphic. It results mainly from the decomposition of other minerals rich in iron. As a staining or coloring agent, it is probably more abundant than red hematite. It also occurs in large masses, and is a valuable iron ore.

Luster.—Dana* in his "System of Mineralogy" gives several kinds of luster as follows: metallic, the luster of metals; adamantine, the luster of diamonds; vitreous, the luster of broken glass; resinous, the luster of yellow resin; greasy, as that of eleolite; pearly, like pearl; silky, like silk. These lusters have different degrees of intensity, being either splendent, shining, glistening or glimmering. When there is a total absence of luster, the mineral is characterized as being dull.

Magnetite.—Magnetite is commonly known as magnetic iron ore. It is composed of iron and oxygen and has the formula: Fe_3O_4. The hardness is 5.5 to 6.5.

Magnetite is one of the commonest constituents of the igneous and metamorphic rocks, and is most often present in small grains or crystals scarcely visible to the naked eye. When present in larger individuals it is easily recognized by its brilliant black luster and the property which it has of being readily attracted by the magnet. Magnetite is not only widely disseminated in grains, crystals, and irregular patches through the igneous and metamorphic rocks, but it also occurs in large beds, constituting a valuable iron ore. Magnetite alters slowly to yellowish brown limonite "which impregnates the surrounding rock."

Marble.—Marble is the metamorphosed equivalent of limestone and is of sedimentary origin. Its composition is the same as that of limestone or dolomite but it is usually compact and thoroughly crystalline. The color of marble varies widely through all shades of white, yellow, brown and red. Sometimes it is beautifully variegated. A crystalline limestone is quarried in the southeastern part of this state, which has all the properties of marble and is so-called by the quarrymen. Marble is a very useful stone both for building, monumental, and ornamental purposes. It is especially desirable for interior decorations.

The public are in the habit of confusing marble with granite. The two are altogether different in composition and origin. The first is of aqueous and the second of igneous origin. The first is composed of calcite or dolomite and the second of quartz, feldspar and mica or hornblende.

Mica—As in the case of feldspar, there are several varieties of mica differing from one another either in the combination, or in the relative amounts of the elements of which they are composed. The two most important species are muscovite and biotite. Muscovite contains various proportions of the elements hydrogen, potassium, aluminum, silicon, and oxygen, while biotite differs mainly in containing, in additon to the above named elements, magnesium and iron. The hardness of muscovite is 2-2.5, while that of biotite is 2.5-3. Mica is distinguished from other associated minerals by its easy and close cleavage. It has the appear-

*A System of Mineralogy, E. S. Dana, p. XXXIV.

ance of being composed of very many exceedingly thin, glossy sheets, piled one upon another. Each sheet or folio can be scaled off with the blade of a pen-knife, or often with the finger nail. Biotite is generally black or very dark brown, owing to the iron in its composition. Muscovite is ordinarily distinguished from biotite by its white or silvery white color. The dark color of some rocks is largely due to the abundance of biotite in their composition, while many of the gray granites owe their color partially to the presence of muscovite.

Biotite is altered very slowly to other compounds by exposure to the atmosphere. The resulting products of decomposition are iron oxide, quartz, chlorite, and a mixture of the carbonates. Muscovite, under the same conditions, decomposes more slowly than biotite. The alteration of biotite takes place along the cleavage planes or between the laminae, which hasten decomposition by furnishing a larger working surface to the agents of decomposition.

Mica is an essential constituent of granite, gneiss, and many other igneous rocks. It also occurs to a less extent in certain of the sedimentary rocks, of which micaceous sandstone is an example.

Olivine.—The olivine group is now more correctly known as the crysolite group. The different species differ somewhat in composition, being composed of varying proportions of magnesium, calcium, iron, and manganese, in combination with silicon and oxygen. The hardness ranges from 6 to 7. The predominant color is what is commonly known as olive green. The luster is vitreous. Olivine is a constituent, mainly, of the more basic igneous rocks, such as diabase and gabbro. It alters very extensively to chlorite, talc, and serpentine.

Onyx.—True onyx is an agate-like stone, consisting of layers of silica of different colors. This stone is not found in Missouri in commercial deposits. The so-called Missouri onyx corresponds in composition to the Mexican onyx, which usually has the chemical composition of a limestone. It is formed in caves in the same manner as stalactites and stalagmites, by the waters that drip through the roof or enter the caves from the sides. This so-called Mexican onyx is usually banded, frequently consisting of irregular, various colored layers which when polished, form a very beautiful stone for decorative purposes.

Ophitic.—A term applied to a rock texture in which the augite "is separated into thin plates by interposed lath-shaped crystals of plagioclase."

Pyrite.—The chemical composition of pyrite is iron and sulphur (FeS_2). The hardness is 6 to 6.5. Common iron sulphide or pyrite proper, is recognized by its cubical shape and bright yellow color. The less common form of iron sulphide, known as marcasite, has a much lighter, almost gray color, and is softer than common pyrite. The occurrence of iron sulphide in both forms is very wide spread, being found alike in eruptive, sedimentary, and metamorphic rocks. Both compounds decompose quite readily, but pyrite proper is less affected by atmospheric conditions than marcasite. This is due to the fact, that much of the iron in the marcasite exists in the ferrous state, while that in the pyrite is more largely in a ferric condition.* Under the same conditions, the ferric compounds are much more stable than the ferrous, and hence the greater readiness with which the marcasite decomposes. The decomposition products of the two minerals also differ to some degree. The decomposition of pyrite results, as a rule, in the formation of limonite and free sulphur, while that of marcasite results in the formation of ferrous sulphate, although, when under water, limonite is also largely formed.

Pyroxene.—The composition of the mineral species included under the general name of pyroxene is nearly the same as that of the species included under the amphibole group. The individuals of this group are ordinarily composed of two or more of the elements magnesium, calcium, iron, manganese, sodium, and lithium,

*Mr. A. P. Brown, Proc. Amer. Phil. Soc., Vol. XXXIII, 1894, p. 225.

in combination with silicon and oxygen, with the addition in certain of the important species, of aluminum, as an essential constituent. The hardness varies from 5 to 6, but in some of the less common species reaches as high as 7. The color and luster of the cleavage faces are essentially the same as in the preceding amphibole group. As has been previously observed, it is difficult to distinguish the members of this group from those of the amphibole. The only ready means is through a determination of the cleavage angles, or a knowledge of the crystal forms. The most important rock forming member of this group is augite, which name is often used synonymously with pyroxene.

Pyroxene is mainly a constituent of igneous rocks, being an important constituent of many of the granites, gneisses, and especially of the more basic rocks.

Through the weathering processes pyroxene is slowly decomposed, altering into chlorite, calcite, and epidote. Under given conditions pyroxene weathers somewhat more rapidly than amphibole, and for this reason is considered a less stable compound.

Quartz.—The chemical composition of quartz is silicon dioxide ($Si O_2$) which is a combination of the two most abundant known elements, silicon and oxygen. It is one of the hardest of the common minerals, being seven in the scale of hardness. It will readily scratch glass and most of the other common minerals. It possesses no ready cleavage, having as a rule a conchoidal fracture. As a rock making constituent, quartz is generally colorless, but when found alone it is frequently brown, yellow, purple, milky white, or pink. When occurring alone or in crystal aggregates, the quartz individuals often have very perfect crystal faces, but as a rock making constituent the individuals generally have round, oval, or irregular outlines.

Quartz is one of the most abundant minerals. The glistening sand which forms the bars in many of the larger rivers is mainly quartz. The white and yellow particles which are caught up by the wind and eddied here and there in small dunes over some of our farms, are mainly quartz. This loose sand is largely a result of the decomposition of sandstone, which is composed mainly of quartz. Quartzite, as the name implies, is composed essentially of quartz. Among the igneous rocks, such as granite, rhyolite, and gneiss, quartz is a prominent constituent. Rocks which do not contain more or less quartz are the exception rather than the rule.

Among all the common rock-forming minerals, quartz is the most permanent. It is very hard and resists, to a high degree, any attempt to break or crush it. As a result of weathering it is often broken into smaller particles, but it is decomposed and taken into solution only with difficulty.

Rift.—This structure has been defined in the discussion of rock structures, in the first part of this chapter, as the plane of flattening, or the direction of easiest parting developed in certain igneous rocks.

Rhyolite.—The rocks which have been placed under this subdivision have essentially the same chemical composition as granite. They differ mainly in texture and mineralogical composition, occasioned by the entirely different conditions under which they have been formed. In contra-distinction to the granites, which are formed deep below the surface, these rocks are formed at or near the surface of the earth.

Porphyritic rhyolite, commonly known as porphyry, is the only variety of this kind of rock which we have occasion to consider. In this rock, quartz and feldspar are the first minerals to crystallize out from the magma, and make up the porphyritic constituents in the rock. Sometimes feldspar alone is present, and again both quartz and feldspar are found among the porphyritic individuals. The remainder of the magma is supposed to have cooled so rapidly as to permit of only partial crystallization. The rock, as a rule, has a dark, dense background, through

which are disseminated numerous large, lustrous crystals of feldspar or quartz, or frequently both. These porphyritic constituents of rhyolite generally differ from those of granite in having well defined crystal outlines. The matrix of porphyritic rhyolite, as it now occurs, is often composed of a dense mass of microscopic crystals of quartz and feldspar. In other instances the matrix may be entirely or in part amorphous.

Run.—This structure has been defined as the plane, normal to the rift, extending in the direction of the elongation of the porphyritic crystals occurring in rhyolite and other igneous rocks.

Sandstone.—The deposit which is found on the bottom of the ocean beyond the conglomerate belt and in deeper water is composed of small particles of sand. When this is deeply buried beneath later sediments and the interstices become filled or partly filled with materials deposited from percolating waters, it is transformed into a rock known as sandstone.

The sandstones vary considerably in composition, but in all cases the preponderant original constituent is round to subangular grains of quartz. Feldspar or calcite may constitute a considerable portion of the rock, in which case it is called either a feldspathic or calcareous sandstone. Clay may be so intermingled with the quartz grains as to give the rock the name argillaceous sandstone. Mica may also be abundant, and the rock is then called a micaceous sandstone.

The original grains which compose the rock generally have roundish outlines, owing to their having been water worn. The individuals, therefore, do not interlock as in the case of the igneous rocks. When first deposited small spaces exist between the grains, but due to consolidation from superincumbent pressure, these spaces may be reduced in size, and through cementation they are either partly or wholly filled by material from extraneous sources.

The kind of cementing material which binds together the grains will depend chiefly upon the mineral matter carried in solution by the water which has percolated through the rocks, although the mineral particles composing the rock may contribute to the force which brings about a precipitation of the cementing material. The more important cementing materials are calcium carbonate, iron oxide, and silica.

It is evident that the hardness of a rock depends upon the state of aggregation, as well as upon the hardness of the individuals composing of the rock. The hardness of quartz is 7, but this is not the hardness of a rock composed entirely of quartz. The hardness of a rock depends chiefly upon the cementing material and the manner in which the grains are united. The efficiency of the cement will depend not only upon its inherent characteristics, but also upon the affinity which exists between the grains and the cement. The hardest and most durable cement is silica. A sandstone in which the individuals are completely cemented with silica is one of the hardest and most durable rocks. Sandstone in which the cementing material is calcium carbonate is softer and less durable than the former. Calcite is one of the sofest of the important minerals of building stone, and breaks very readily into small pieces, due to its cleavage. It is also quite readily dissolved in carbonated waters. A sandstone in which the individuals are cemented with iron oxide is usually less strong than one cemented with either silica or calcite. As a rule, iron oxide is the least important of the three cements.

Any estimate of the strength or durability of a rock should take into consideration the conditions of cementation. In comparing the hardness and durability of sandstone, the relative amount of cementing material, the size of the grains, and the completeness with which the cement has filled the interstices, as well as the kind of cement and mineral constituents, should be taken into consideration.

Alterations of sandstone are mainly the result of additions or subtractions

of mineral matter, usually silica. Quartz, as has been previously stated, does not decompose readily although small amounts may be taken into solution and carried away by percolating water. The cementing materials and the subordinate constituents, such as feldspar, mica, calcite, and iron oxide (or sulphide), are alone subject to alteration in the sense of decomposition. Feldspar and mica break down into their various alteration products, and calcite is often dissolved and reprecipitated as the sulphate. Ordinarily iron oxide, in the form of hematite, is reasonably stable; in the form of the carbonate or sulphide, it is readily decomposed, and becomes a source of discoloration.

Schistosity.—This strucure has been defined as wavy cleavage planes in rocks. It has been discussed in detail in the first part of this chapter.

Shale.—In deeper water but mainly in the shallow parts of the ocean, beyond the sandstone belt, still finer sediments are deposited in the form of clay. These deposits, after passing through the ordinary process of consolidation, are transformed into a rock, which is known as shale. When metamorphosed they pass into slate. These rocks are not among the important building stones of Missouri and will not be further considered.

Shaly.—This is a term which is applied to thinly bedded rocks in which the layers are separated by thin leaves of shale.

Shelly.—This term is used synonymously with shaly.

Stratification.—The planes along which a sedimentary rock has a natural capacity to part most readily, are known as stratification planes.

Stratum.—A stratum is commonly known as a layer of rock between two stratification planes. Popularly, the term stratum is used synonymously with bed and layer, although it is thought that its use should be confined to a layer of rock between stratification planes.

Streak.—The streak is the color of the mineral when powdered, and in the case of the softer minerals is obtained by scratching a piece of porcelain with the mineral which is to be identified. As a means of determining the minerals of building stones, this quality is not important except perhaps in two or three cases.

Stylolite.—This term is applied to the irregular toothed jointing planes occurring in limestone and dolomite. This structure is illustrated in Plate XXVIII.

Suture Joint.—This term is used synonymously with stylolite.

Syenite.—This is an igneous rock very closely allied to granite, and usually known, commercially, as granite. It consists chiefly of orthoclase feldspar and one or more of the ferro-magnesian minerals biotite, amphibole, and pyroxene. Among the accessory minerals are zircon, magnetite, hematite, apatite, eleolite, analcite, etc. It differs from granite chiefly in the absence of quartz.

Talc.—Talc is composed of hydrogen, oxygen, iron, magnesium, aluminum, and silica, united in different proportions. It is usually foliated, but frequently massive or fibrous. Talc has a peculiar greasy feel which furnishes, as a rule, a ready means of distinguishing it from associated minerals. The color varies from apple green to white or silvery white. The luster is often pearly on cleavage faces. Talc is widely disseminated through the igneous and metamorphic rocks.

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of mineral matter, usually silica. Quartz, as has been previously stated, does not decompose readily although small amounts may be taken into solution and carried away by percolating water. The cementing materials and the subordinate constituents, such as feldspar, mica, calcite, and iron oxide (or sulphide), are alone subject to alteration in the sense of decomposition. Feldspar and mica break down into their various alteration products, and calcite is often dissolved and reprecipitated as the sulphate. Ordinarily iron oxide, in the form of hematite, is reasonably stable; in the form of the carbonate or sulphide, it is readily decomposed, and becomes a source of discoloration.

Schistosity.—This strucure has been defined as wavy cleavage planes in rocks. It has been discussed in detail in the first part of this chapter.

Shale.—In deeper water but mainly in the shallow parts of the ocean, beyond the sandstone belt, still finer sediments are deposited in the form of clay. These deposits, after passing through the ordinary process of consolidation, are transformed into a rock, which is known as shale. When metamorphosed they pass into slate. These rocks are not among the important building stones of Missouri and will not be further considered.

Shaly.—This is a term which is applied to thinly bedded rocks in which the layers are separated by thin leaves of shale.

Shelly.—This term is used synonymously with shaly.

Stratification.—The planes along which a sedimentary rock has a natural capacity to part most readily, are known as stratification planes.

Stratum.—A stratum is commonly known as a layer of rock between two stratification planes. Popularly, the term stratum is used synonymously with bed and layer, although it is thought that its use should be confined to a layer of rock between stratification planes.

Streak.—The streak is the color of the mineral when powdered, and in the case of the softer minerals is obtained by scratching a piece of porcelain with the mineral which is to be identified. As a means of determining the minerals of building stones, this quality is not important except perhaps in two or three cases.

Stylolite.—This term is applied to the irregular toothed jointing planes occurring in limestone and dolomite. This structure is illustrated in Plate XXVIII.

Suture Joint.—This term is used synonymously with stylolite.

Syenite.—This is an igneous rock very closely allied to granite, and usually known, commercially, as granite. It consists chiefly of orthoclase feldspar and one or more of the ferro-magnesian minerals biotite, amphibole, and pyroxene. Among the accessory minerals are zircon, magnetite, hematite, apatite, eleolite, analcite, etc. It differs from granite chiefly in the absence of quartz.

Talc.—Talc is composed of hydrogen, oxygen, iron, magnesium, aluminum, and silica, united in different proportions. It is usually foliated, but frequently massive or fibrous. Talc has a peculiar greasy feel which furnishes, as a rule, a ready means of distinguishing it from associated minerals. The color varies from apple green to white or silvery white. The luster is often pearly on cleavage faces. Talc is widely disseminated through the igneous and metamorphic rocks.

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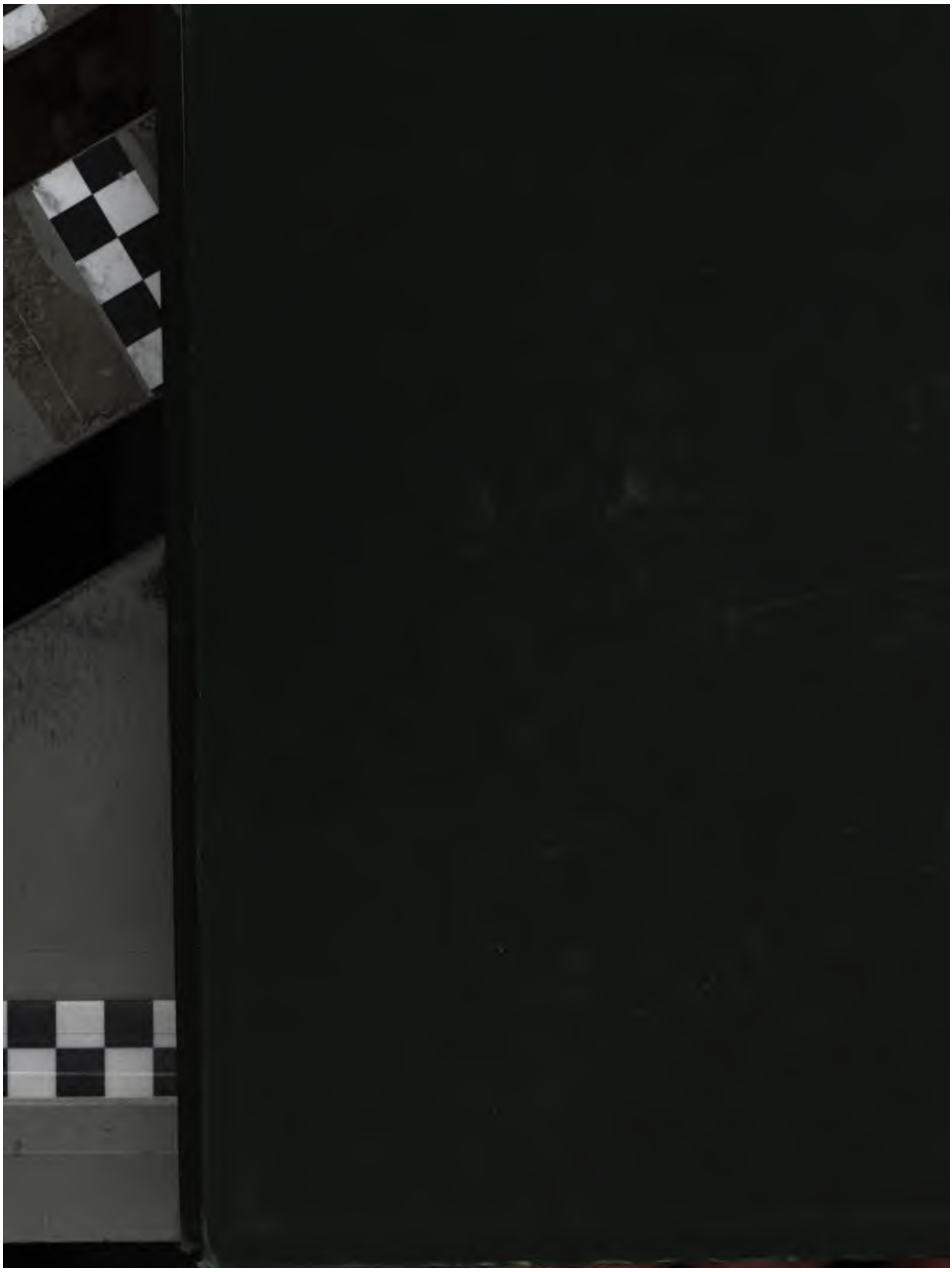
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